Journal of
Experimental Psychology

VOL. 24, NO. 1 JANUARY, 1939

CEREBRAL CIRCULATION PREVAILING DURING SLEEP AND HYPNOSIS *

BY J. WALLACE NYGARD

North Carolina State Board of Charities and Public Welfare

The General Problem

This study is a comparison of the cerebral circulation prevailing in natural sleep with that prevailing in hypnosis, as well as an investigation of the adequacy of the so-called 'cerebral circulation theories' of sleep. These have been of two opposing types: one group espousing cerebral anæmia as the cause of sleep, and another the cerebral congestion view.

Mosso (**13**) in 1881 from observations on three trephined patients during sleep concluded that sleep is associated with an increased volume of blood in the limbs as a result of relaxed vessels and a coincident decreased supply to the brain. Howell (**8**) continued the plethysmograph study of the extremities during sleep and, since he found the volume of the periphery to increase during sleep, he assumed that there must necessarily be a reduced volume in passive brain vessels. From these experiments, Howell postulated the cerebral anaemia theory of sleep. This assumes that the sympathetic

* Dissertation submitted in partial fulfilment of the Doctoral Degree in the Department of Psychology, University of Michigan. The writer wishes to express gratitude to Dr. John F. Shepard for helpful suggestions and to Dr. Robert Gesell, of the Department of Physiology of the University of Michigan, and Dr. Phillip Bard, of the Department of Physiology at Johns Hopkins University, for extending the use of their laboratories during this investigation.

center becomes fatigued from continued activity during the day, and, as a result of this fatigue, those blood vessels of the body supplied with vasomotor nerves relax. The relaxation results in an increase of volume and a reduction in blood pressure in the periphery which, in turn, is sufficient to produce a diminution in volume of the passive brain vessels (cerebral anæmia), causing sleep. Such a theory seemed very plausible. Bayliss and Hill (1), Roy and Sherrington (14), Hill (7), and other investigators at that time envisaged the cerebral vessels as being without vasomotor fibers and therefore regulated entirely indirectly by circulation changes in other parts of the body. If the blood volume could be shown to increase in the extremities during sleep, and the blood pressure to decrease, what could be more natural than to believe that there would be a diminution in the intracranial circulation?

Studies by Brush and Fayerweather (4), Blackenhorn and Campbell (2), Landis (11), Brooks and Carrol (3), and others have clearly shown that the blood pressure does decrease in sleep, and their data supports Howell's viewpoint. However, the assumption that the cerebral vessels act only passively to circulatory changes elsewhere in the body is one that recent investigators have rejected in the light of newer experimental studies. It is now conceded that the cerebral vessels have their own vasomotor nerve supply and may vary independently of the circulation changes elsewhere in the body. Numerous studies have shown this indirectly but it remained for Forbes and Wolff (5) in microscopic photography of the pial vessels through an implanted skull window in the dog to give the most direct evidence for such a view. Other workers corroborated the findings of Forbes and Wolff, and with other technical advances have revealed without a doubt that brain vessels actively change in size, and that these vessels may vary independently of the general blood pressure.[1] Moreover, even Mosso's original experimental data from which Howell's theory derives its strength have been contra-

[1] For an excellent review of the literature of this subject, the reader is referred to Wolff, H. G., The cerebral circulation, *Physiol. Rev.*, 1935, 16, p. 545.

dicted by more recent experimental work done by Shepard (**15**). In an extensive study of two trephined cases, he has shown that, contrary to the views held by Mosso, sleep is characterized by a long and sustained increase in volume. Similar results were found by Stevenson, Christianson and Wortis (**16**) on several brain hernia cases. However, the latter authors, as a result of their study, developed a cerebral congestion theory of sleep which we will later have reason to criticize. They envisaged the sympathetic center in the brain as becoming periodically fatigued with a resulting vaso-dilatation of both brain and periphery. This vaso-dilatation might cause sleep in either of two ways: "the brain volume would be increased with a consequent pulling apart of the neurons (diaschisis)"; or "the cerebrospinal fluid would be increased in pressure within the brain, especially in the pericullular spaces, thus altering the conductivity of the synapse."

Gibbs (**6**) has developed a technique in which brain circulation in individuals with intact skulls can be studied. By a thermo-flow recording needle he measures the blood flow as it leaves the brain through the internal jugular vein. Gibbs found no difference in circulation between the waking and sleeping states.

Previous to this investigation there seem to have been no attempts made to observe the cerebral circulation prevailing during hypnosis. The volume of blood in the arm during hypnosis, as determined by a plethysmograph, has been compared to that during sleep by Walden (**19**). He found that the circulation changes during hypnosis were, in general, the reverse of those found in sleep, which led him to suggest that the cerebral circulation may also be different. However, other workers (**17**, **18**) have not found the prolonged gradual constriction in the periphery that Walden found so characteristic of hypnosis. Numerous investigations, in fact, have shown that the resemblance between hypnotic sleep and normal sleep is only superficial. Hull has pointed out in his book that actually hypnotic sleep resembles the waking condition more than it resembles natural sleep. Since the appearance of Hull's book, Jenness and Wible (**19**), in a well controlled

study comparing respiration and heart action in sleep and hypnosis, report cardiac rate and respiration as lowered in sleep but not in hypnosis. Similarly, Loomis, Harvey, and Hobart (**12**) in measuring brain potential waves during induced hypnosis report that the waves in the trance condition resemble those in the waking condition rather than in sleep.

Subjects

The subjects used in this study were three young males and one female. Each of these individuals had had a portion of the skull removed, making possible measurements of cerebral circulation changes.

Subject No. 1 (female) had been admitted to the University Hospital on February 19, 1936 with a skull fracture and right extra-cerebral hemorrhage as a result of a toboggan accident. A decompression and right temporal craniatomy was performed. The extra-cerebral hemorrhage was evacuated, and a small portion of the cortex, which was softened, was also removed. Observable slight Jacksonian convulsions were alleviated by operation. Recovery was uneventful. She attended college during the school year of 1936–1937 with no observable effects of the injury and experiments were run with her from January to May, 1937. The bone defect was in the shape of an ellipse, measuring about 6.5 cm in its longest and 4.5 cm in its shortest diameter. Pulsations in the region of the defect were easily noticeable. The scalp was loose and free and the hair could be parted away from the defect so that shaving the head was unnecessary.

Subject No. 2 (male) had been admitted to the University Hospital with a compound comminuted fracture of the frontal bone, as a result of an automobile accident. The brain was oozing out of the lacerations. On November 17, 1935 a debridemant skull fracture and partial craniectomy were performed. A part of the frontal lobe of the brain was removed and the frontal sinuses excised. Both olfactory nerves were destroyed. Since release from the hospital four convulsions have been reported but none during the school year 1936–1937 when we carried on our observations. Experiments with this subject ran from November, 1936 through May, 1937. The injury had healed well. No plate was used. The defect in the skull measured about 7.5 cm by 2.5 cm and had relatively even edges. The skin overlying the defect had a considerable dip, but was loose and free and could be observed noticeably to pulsate with each heart beat.

Subject No. 3 was an epileptic boy with a left temporal decompression. We include several observations during normal sleep in this subject, but actually they were incidental observations obtained while making a study of intra-cranial pressure in epilepsy.

Subject No. 4 (male) had a compound skull fracture as a result of an automobile accident. A right subtemporal decompression with the dura incised was done at Johns Hopkins Hospital, October 30, 1930. Recovery was uneventful and complete. The experiments on this subject were conducted in the physiology department of Johns Hopkins University during the summer.

Experimental Rooms and Apparatus

Two adjoining rooms, not interconnected but both opening into a large laboratory, were used in this investigation. In one room were set up the recording apparatus,

piston recorders, Marey tambour (recording device for pneumograph), two signal magnets, syringes, and special blood pressure apparatus. The other room was the sleeping room with bed and necessary bed clothes. Between the sleeping room and apparatus room there were holes in the wall through which thick walled rubber tubing connected the recording devices with the brain tambour system, pneumograph, and scalp control attached to the subject. The bed and the subject were in semi-darkness with only enough light entering through the open door so that experimenter could observe the sleeper. The experimenter usually sat in the doorway at the head of the bed. Nearby was placed paper, pencil, and signal key to record movements of the sleeper on the kymograph paper. An assistant supervised the apparatus, but, once the writing levels were recording, the apparatus needed very little attention, so that the assistant usually watched the recording while the experimenter was free to observe the sleeping subject. The temperature of the room was recorded during each experiment at various periods during the night, but, since it seldom varied more than one degree during the night, the effects of temperature changes are negligible. It was necessary, however, to wait 15 minutes after the subject was placed in the apparatus to allow for any possible temperature changes in the tambour system to attain a normal level.

To measure the volume of the brain in subject 2 a plaster of paris cast of the forehead was taken, and from it was constructed a tambour that curved with the forehead and rested comfortably inverted on the bone adjacent to the depression. A thin dam of rubber was stretched over the surface, so that when the tambour was placed over the defect, the tension of the rubber dam held the skin down in the defect of the skull, but would move with each heart beat and any changes in volume. Some of the experiments were conducted with a piece of balsa wood attached to the rubber dam to press the scalp still further down in the defect. The tambour system was sealed in place by plastic modeling clay and held in position firmly by a broad bandage wrapped around the head from front to back. For each of the subjects 1, 3 and 4 a tambour was constructed to rest comfortably inverted on the bone adjacent to the defect and attached to the rubber dam of the tambour by means of beeswax was a piece of balsa wood cut to fit the depression. The tambour was held firmly in position by one broad bandage wrapped around the head from front to back. Additional tambours were constructed for two of the subjects to act as scalp controls. In subject 2 the scalp control was placed above the cranial defect tambour on the forehead; on subject 1 on the opposite side from the cranial defect. These served in detecting changes due to movement as well as changes in the vascular bed of the scalp.

The electrically driven kymograph in the apparatus room had wide drums and could carry a nine foot paper. Sufficient smoked papers were always at hand so that a night's work could continue without interruption. All brain tracings and some scalp controls were written by a piston recorder lubricated by distilled water; this was of standard make, having a bore of 1.6 cm and a celluloid writing level of 14.5 cm in length.

Respiration was measured from the thorax by a Sumner pneumograph attached to a Marey tambour.

Numerous other studies have shown that the blood pressure falls with the onset of sleep. We checked this observation with subject 2. We preferred to use the usual ausculation method to determine systolic and diastolic pressure. Readings were taken on the right arm before and at irregular periods during sleep.

In addition to these irregular readings, we also set up a continuous method of measuring blood pressure that would record changes in blood pressure that appear as waves, synchronously with respiration and brain volume changes. To obtain these

continuous records of blood pressure, a modified Erlanger capsule and mercury manometer was set up in the apparatus room. The pneumatic bag on the left arm of the subject in the sleeping room was inflated from the recording room slightly above diastolic pressure as previously determined on the other arm by the ausculation method. A suitable Marey tambour attached to the modified Erlanger capsule recorded these changes synchronously with respiration and cranial defect changes on the smoked drum. It should be made clear that this latter method does not record quantitative measurements but does show general changes in pressure, especially the respiratory waves of blood pressure. It was not possible to keep the pneumatic bag continually inflated during the act of going to sleep, but we were able to obtain records while awake and during periods of as much as eight minutes duration while asleep without awakening the subject.

PROCEDURE

Most of the records were obtained from the subjects on the left side position. Subject 2 also preferred a side position in sleeping, but since the cranial tambour, in his case, recorded better with the subject lying on his back, he was required to sleep in this position.

The procedure in all sleep observations was very simple. After the apparatus was attached and due allowance made for temperature adjustment, the lights were turned out and the kymograph started. Our subjects did not have any difficulty in falling asleep rather quickly. After a suitable period of sleep, the subject was aroused. To have corresponding data on the awake condition we at times gave the command, "wake up!" when the subject was actually awake.

Minor variations in general procedure were introduced on certain evenings to answer such questions as:

1. Do changes in respiration have any influence on the volume curve?
2. Do the circulatory changes precede sleep or are they the result of sleep?
3. Is the blood pressure reduced in sleep as reported by so many authors?
4. Does the increase in the vascular bed of the scalp by tightening of the bandage give a simulation of increased volume in the cranial defect tambour?

The cerebral circulation prevailing during hypnosis was not studied until sufficient data of sleep had been obtained. An attempt was made to induce a deep hypnosis in all subjects, but it was successful only in two subjects, namely, subjects 1 and 4. With suitable suggestions these subjects appeared to be in a profound somnambulistic hypnotic trance, with catalepsy demonstrated by supposedly involuntary retention of the arm in position where placed, and an apparent amnesia post-hypnotically for all trance events and suggestions. All the experimental sessions on hypnosis were held at the same hours in the evening as the sleep experiments.

Before any experiments were conducted upon induced hypnosis, the subject was trained until only a few words sufficed to induce the trance. Post-hypnotic amnesia, local analgesia, post-hypnotic suggestions, hallucinations, and catalepsy were demonstrated in these training series. The procedure used in actual experimental observations corresponded with that of the study of sleep. A brief record was taken while awake and then hypnosis was induced. To insure the subject was not in normal sleep or awake, the subject was tested at intervals by catalepsy (retention of the arm in position where placed).

We differed from the usual procedure on two occasions in each subject by inducing the hypnosis before the apparatus was attached. This variation was introduced so

that other tests than catalepsy could be used to measure the depth of hypnosis obtained. On some evenings the interval testing of hypnosis was dispensed with, on the assumption that testing for hypnosis might act as a suggestion for hypnosis, and thus keep the trance condition from merging into sleep. On these evenings only one test instead of tests at approximately 15 or 20 minute intervals followed the hypnosis suggestion. In subject 4 interval testing of suggested analgesia was also introduced to insure that hypnosis had not merged into sleep.

Results of Sleep Observations

We have a total of thirty-four experiments on four subjects in going to sleep, during sleep, at awakening, and after awakening. In addition, there will be discussed some minor experiments that were designed to answer certain questions that arose.

All brain tracings were written by a piston recorder having a bore of 1.6 cm in diameter, with a writing lever of 14.5 cm from tip to axis. The distance from the axis to the insertion of the piston rod was 3.2 cm. The actual movement of the piston would therefore be given approximately by dividing the movement of the writing point by 4.5. Due to the large bore, it was obviously not delicate enough to record changes in the vascular bed of the scalp but readily recorded the pulsations from the region of the defect, since these were very marked. However, to test whether the dilatation of the vascular bed could, by tightening the bandage, produce a simulation of increased volume in the region of the defect, it was necessary to test with a control tambour placed over a region of intact skull. In subject 1 the control tambour was identical with the tambour overlying the defect except that the balsa wood was cut flat instead of rounded to fit the defect. The control tambours, when used, were placed on the forehead directly above the cranial defect tambour in the case of subject 2, and on the opposite temporal bone from the defect in the other subjects. Although the scalp controls were written by a piston recorder of smaller bore and therefore more delicate than the piston recording brain volume, no increase in volume during sleep was apparent from these controls. They did serve a very useful purpose, however, in recording artificial changes due to movement. Notes were taken by the observer of all movements of the sleeping sub-

ject. An electric indicator controlled by a signal key marked the point on the smoked drum where the notes were taken. It became a simple matter to detect artificial changes in the brain volume curve with the scalp control. Movements always produced a sharp rise and fall unaccompanied by the usual pulse form changes. True vasomotor changes were always less abrupt with full pulse form showing at all times. The largest source of movement was not change of position in sleep, but the stretching of strained muscles after being awakened from a period of sound sleep. These always appeared in the volume curve as a sharp break. In spite of being shown the necessity for doing so, subjects had difficulty in controlling the desire to stretch after being roused.

Lengthy records were taken of the subjects awake at rest, but nowhere were considerable volume changes observable. The pulse form awake is characterized by a pulse low in amplitude, with a low dicrotic notch at, or very near the base of the wave. (See last portion of Fig. 1, and first portion of Fig. 2 of Plate I.)

When sleep ensues the amplitude of the arterial pulse increases markedly, and the dicrotic wave becomes elevated and much more prominent. With these pulse changes the volume of the blood in the brain increases. The pronounced pulse and increased volume are probably due to relaxed vessels. The rise in volume is gradual and usually rhythmical until it reaches a maximum which is sustained at a fairly constant level during deep sleep.

On being awakened from sound sleep by command, the volume falls a to normal level, although at times there may be a brief rise before the fall in volume occurs. The pulse form continues high in amplitude with high prominent dicrotic wave for some times as long as 50 seconds after awakening and then with the fall in volume the characteristic pulse form of the waking state appears. (See Fig. 1, Plate I.)

All our record consistently gave sustained increased volume during sleep, but we had to introduce variations in our usual procedure to determine whether the rhythmical rise in volume precedes sleep or occurs after sleep ensues. This question is

very important in relation to the so-called 'cerebral congestion' theory of Stevenson et al. They, like Howell, believe that the sympathetic center in the brain controlling vasomotor tone becomes periodically fatigued, but, unlike Howell, believe it produces vaso-dilatation of the blood vessels of the brain sufficient to pull apart the neurones or alter the synapse and produce sleep. To make an explanation of sleep dependent upon a mechanical pulling apart of the neurones or alteration of synaptic connections, it is necessary to show that the supposedly fatigued sympathetic center produces the cerebral congestion before or as sleep ensues, and the congestion disappears before or as the subject awakens.

In our study we found it relatively easy to show that the subjects report being awake, after arousal from sound sleep, while the volume curve is still high with the characteristic pulse form of sleep; a situation that would be unlikely if contractility of neurones, or alteration of synapse from intracranial pressure, were the cause of sleep. It was very difficult on the other hand, to show that the increased volume did not precede the onset of sleep, because there are no adequate criteria to distinguish the moment sleep ensues, if there is such a moment. The observer made notations of when snoring appeared, but that proved an ineffective criterion. Critical examination of the respiratory tracing also proved of only little value.

Another method used in an attempt to answer this question was to have several of the subjects press a key until impairment of consciousness ensued. The rise in volume with sleep did not appear until after pressing the key had stopped, but this again is a poor criterion of the moment sleep occurs. Probably the best evidence that the circulation changes are the result rather than the cause of sleep was obtained on the occasions the subject was aroused just as the volume curve began to ascend in the characteristic fashion of sleep. The introspections on these occasions indicated that the subject had already fallen asleep. The subject could not be very positive that he or she had been truly asleep, but it was agreed that some impairment of

consciousness had already occurred. After due consideration that the criteria set up to determine the exact moment sleep ensues are not adequate, we do believe that the circulatory changes are the result rather than the cause of sleep.

The effect of the command "Wake up!" on the volume curve of sleeping subjects has already been discussed, but there are interesting differences produced by the same auditory stimulation given with the subjects awake that should be mentioned. Whereas in sleep the command arouses the subject and produces a diminution in volume with a pulse of smaller amplitude, the same command while awake produces a short temporary rise in volume without definitely changing the pulse form. It is interesting to observe that sensory stimulation such as determining of blood pressure, sound of pounding radiators, and other extraneous noises that occurred during the sleep observations, are liable to affect the circulation of blood during sleep even though they do not awaken the sleeping subject. The sensory stimulation evidently acts reflexly upon the vasomotor center, causing a contraction of the relaxed blood vessels. The resulting diminution, however, is never as great as when the subject is actually aroused. This is strikingly similar to observations made on arm volume during sleep by Howell and illustrated in his text book (**9**). Of further interest in this connection is that Loomis, Harvey, and Hobart, in measuring electrical potentials from the brain during sleep, report that here too auditory stimulation which is insufficient to awaken the sleeping subject, produces in some individuals momentary alpha waves that are characteristic of the waking state rather than that of sleep. The best evidence we have that there is a latent period in the contraction of relaxed vessels following auditory stimulation, is from our early experiments. At that time the kymograph motor, which was later repaired, started out with a loud sound and then continued very quietly. Since during sleep, when no changes were apparent in the writing lever, the motor was stopped for lines of reference and to conserve paper, it was possible to detect the temporal sequence of the loud sound of starting with the diminution in volume produced in sleep.

Blood pressure during sleep has been studied by other investigators and found to be lower in sleep than when awake at rest. During sleep we found a sustained increased volume of the blood in the brain, so we were interested in substantiating the lowering of the blood pressure in sleep. Subject 1 would awaken too quickly for blood pressure determinations, but we did get data from subject 2, sufficient to show that the blood pressure decreases a significant amount during deep sleep. The decrease in this subject was from 100 mm/60 mm Hg at rest awake, to an average of 86 mm/60 mm Hg during deep sleep.

The rise in blood pressure when awakened by command is abrupt and as already shown by other investigators may exceed that of the normal awake at rest period. This abrupt rise at awakening occurs while the brain vessels evidently are still relaxed, as shown by arterial pulse of high amplitude and prominent elevated dicrotic. It is conceivable that this sudden increase of blood pressure, occurring at a time when the brain vessels are still relaxed, may be a dangerous period to the individual already having a diseased condition of the cerebral arteries.

To determine the heart action during sleep the volume curve was studied in still another way. Rate of the heart beat was counted while awake at rest, and compared with a corresponding period during sleep. The heart rate, we found, was slightly slower in sleep than awake. Evidently, then, the rise in volume with sleep is accompanied by lowered heart rate and a slight decrease of blood pressure.

Our method of studying changes in the respiration while awake, sleeping, and during induced hypnosis, with the Sumner pneumograph placed over the thorax, is not very adequate in that we do not have records of abdominal breathing. If the breathing decreased during sleep, presumably there might be a slight accumulation of carbon dioxide content of the blood sufficient to act as a stimulus to produce relaxation of the cerebral vessels. Subject 2 demonstrated periodic breathing during sleep. With restricted breathing the volume increased slightly; with deep breathing the volume decreased.

However, in general, sleep in all but one subject showed increased rather than decreased respiration. In spite of this, the volume always remained high during sleep.

Subject 1 maintained a relatively regular respiration throughout sleep with the amplitude of the wave slightly decreased over that awake. However, experiments upon artificially increased breathing followed by shallow breathing while awake clearly showed that the decreased breathing does not explain the marked sustained rise of brain volume and the pulse form that appears in sleep. Restricted breathing awake causes a slight rise in volume without an apparent change of pulse form, whereas in sleep the volume increased markedly with changes in amplitude and form of the arterial pulse.

Results of Induced Hypnosis Observations

There are twenty records of induced hypnosis in two of our subjects. We have described the distinct changes that appear in the cerebral circulation with the onset of natural sleep. With the onset of hypnotic sleep the changes of cerebral circulation did not appear. The cerebral circulation during induced hypnosis resembled the waking state rather than that of sleep. The arterial pulse cannot be distinguished from that in a corresponding wake period in amplitude, or form of pulse wave.

When hypnosis is induced there is a temporary rise in volume without changing the amplitude of the arterial pulse. This, however, is similar to the reaction to all auditory stimuli given to the subject in the normal wake period.

Hypnosis on four different occasions merged into natural sleep with one subject. When this occurred, the brain volume showed the distinct changes found in sleep. We knew that natural sleep had occurred by testing for hypnosis. The subject awakened as soon as the arm was grasped preparatory to testing for catalepsy. This test we found would differentiate hypnosis from the waking state or natural sleep in this subject.

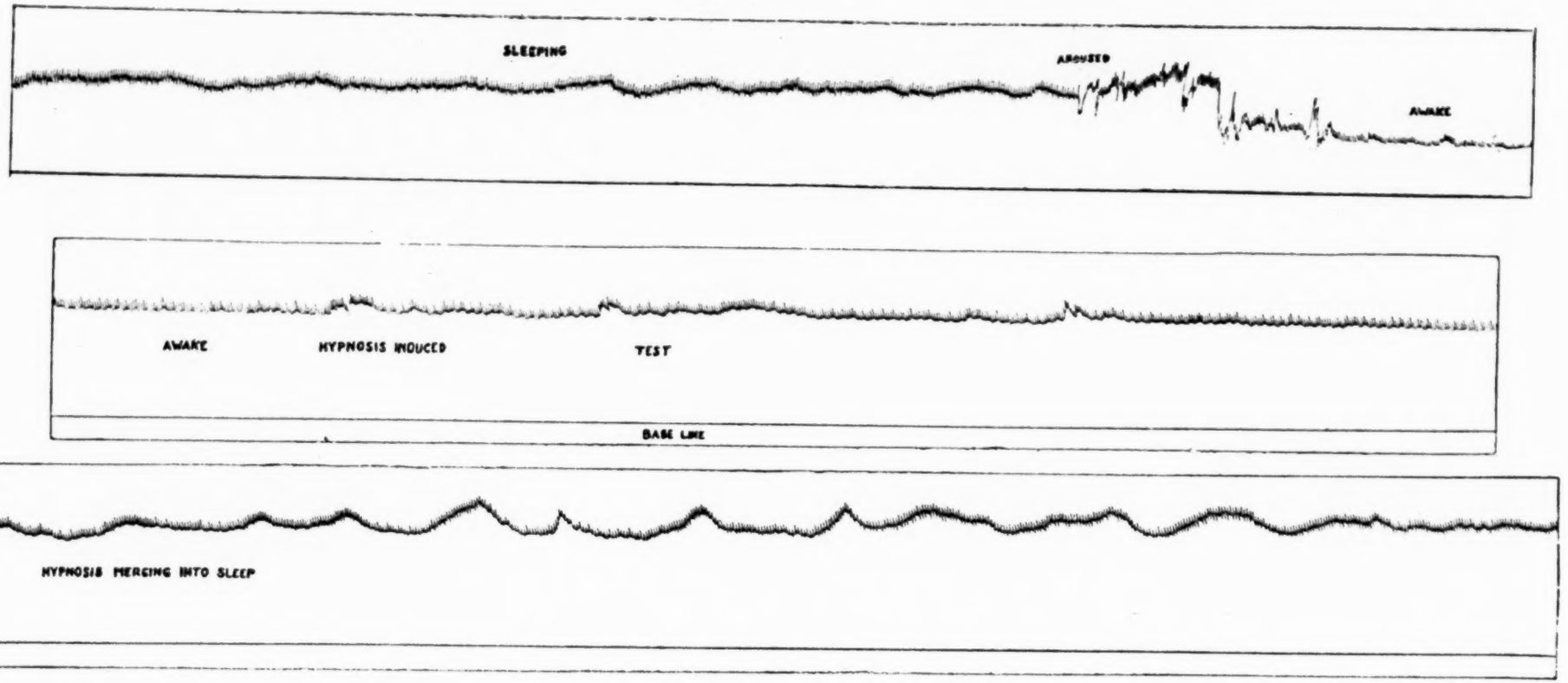
Description of Plates

The observations on cerebral circulation prevailing during sleep and hypnosis can best be illustrated by excerpts from typical records. Unfortunately, due to the expense, only a few of the records are herein published. They have been selected to show the characteristic differences between awake, trance, and sleep.

March 6, 1937. Plate I, Fig. 1. Subject No. 1

The subject was in bed in the laboratory with the apparatus connected and ready to record by 8:20 P.M. After a wait of 10 minutes to allow for temperature adjustment to take place, the lights were turned out in the sleeping room and the recording begun. While the subject was at rest but still awake the command, "Wake up!" was given. Similar awake reactions to the words "Wake up!" had been recorded on other evenings so that comparisons could be made with reactions in sleep. The response in the volume curve while awake was always a short brief rise with no change in amplitude of pulse or position of the dicrotic. The excerpt shown in Fig. 1 is from the second period of sleep. She had been asleep earlier, awakened by command, and allowed to fall asleep again. When sleep ensues, usually from 3 to 6 rhythmical rises are observed in this subject before the volume attains a maximum level which is sustained throughout deep sleep. This excerpt begins 17 minutes after full and sustained volume appeared in sleep. At the point marked 'aroused' the subject awakened quickly to the command, "Wake up!". In spite of a quick awakening, the volume remained sustained for 44 seconds after being aroused with the characteristic pulse form of sleep. Sudden, abrupt rises and falls of the record after 'aroused' are due to stretching tense muscles after a period of sound sleep. These movements are almost impossible to eliminate. In spite of this sharp break upward from stretching, all curves from this subject showed a fall in volume after awakening. Note, however, how slowly the constriction with awakening occurs.

PLATE I


SLEEPING
AROUSED
AWAKE
AWAKE
HYPNOSIS INDUCED
TEST
BASE LINE
HYPNOSIS MERGING INTO SLEEP

April 2, 1937. Plate I, Fig. 2. Subject No. 1

The experiment for this evening was designed as a continuation of the study of hypnosis. We had already obtained a record in which hypnosis merged into sleep in this subject and we were interested primarily in obtaining more of this type. The subject reported being very sleepy. The apparatus was all attached by 8:10 P.M. After a brief observation on the effect of changing from deep to shallow breathing while awake, hypnosis was induced, followed by a test for catalepsy. Near the end of the second kymograph paper of the evening, she was aroused by the same command as was used in normal sleep, namely, "Wake up!" Figure 2 of Plate I is an excerpt taken about 10:15 P.M. at the beginning of the third change of paper. She had been awake for about 10 minutes and the volume curve pointer was still writing at the same level and with similar pulse as at the end of the second paper. Note especially the amplitude of the pulse and the position of the dicrotic. Hypnosis suggestions began at the point where the volume curve ascends slightly. This momentary rise in volume without a change in pulse form is a characteristic response, in all curves obtained during wake or hypnotic periods, to all forms of auditory stimulation whether it be suggestions for hypnosis or the command, "Wake up!".

The second slight rise denotes where the arm was lifted to test for catalepsy; usually the test for catalepsy was made without verbal suggestions but in this instance I suggested: "Your arm is getting more and more rigid." When it attained full rigidity, a suggestion for general relaxation and deeper sleep was given while the arm was placed on the bed. The last portion of the record of Fig. 2 shows the typical form of the cranial volume curve at all times during induced hypnosis. Note that it cannot be distinguished from the pulse that is in evidence while awake. We hoped to let this pulse continue to see if it eventually merged into the characteristic volume change and pulse form of sleep. If and when the volume curve showed the characteristic rise and pulse form of sleep we were prepared to test for hypnosis and not before.

To test for the trance condition at regular intervals may act as a stimulus suggestion for hypnosis. We thought that this interval testing of hypnosis may account for our earlier records never merging into sleep in spite of lengthy records.

April 21, 1937. Plate I, Fig. 3. Subject 1

This 9-minute natural-size excerpt illustrates hypnosis merging into sleep. It was taken from the same record as Fig. 2 about 30 minutes later. During the interim no changes in pulse form or volume were observed. Incidentally, we never obtained sighing, stretching, or position changes during hypnosis, although these were sometimes evident when we studied comparative awake or asleep periods. The piston was still writing at the same level at the beginning of this excerpt as it had been at the end of the excerpt shown in Fig. 1. Sleep probably began just before the first rhythmical rise in the tracing. It took a good deal of study to show when trance or awake periods ended, and sleep ensued. This question, since it required separate experimentation, can be more profitably discussed elsewhere in this paper. Note in this excerpt the rhythmical manner the curve rises when sleep occurs. Accompanying the volume rise are the typical changes in pulse form that occur in sleep in this subject. Note the position of the dicrotic wave in deep sleep at the end of this excerpt. The amplitude of the pulse wave is greater than observed in trance states or wake periods and in addition the dicrotic notch becomes elevated and more pronounced.

Not shown is the sustained increased volume that followed this excerpt. It remained sustained until the operator grasped the arm of the sleeping subject to test for catalepsy as usual. This immediately awakened the subject, and the volume curve slowly descended to the normal level very similar to that shown in Fig. 1.

Introspections were often obtained after a subject had been aroused from either sleep or hypnosis. On one of these occasions she reported, "I think I know now how I can tell whether you awakened me from natural sleep or hypnotic sleep by estimating how sleepy I feel; when I am aroused

from hypnosis I am wide awake immediately, but when awakened from natural sleep, I still feel drowsy."

June 12, 1937. Plate II, Fig. 1. Subject No. 3

This subject is an epileptic boy with a left temporal decompression. We hoped to obtain records during an epileptic seizure but were unsuccessful. This excerpt shows the respiration and brain volume curve and illustrates: sleeping, being aroused, a short wake period, and drowsiness.

July 17, 1937. Plate II, Fig. 2. Subject 4

This excerpt illustrates a normal sleep record with an arousal produced by testing for catalepsy. Elevating the arm always aroused this subject with the same reaction in the volume curve as the command, "Wake up!".

July 19, 1937. Plate II, Fig. 3. Subject No. 4

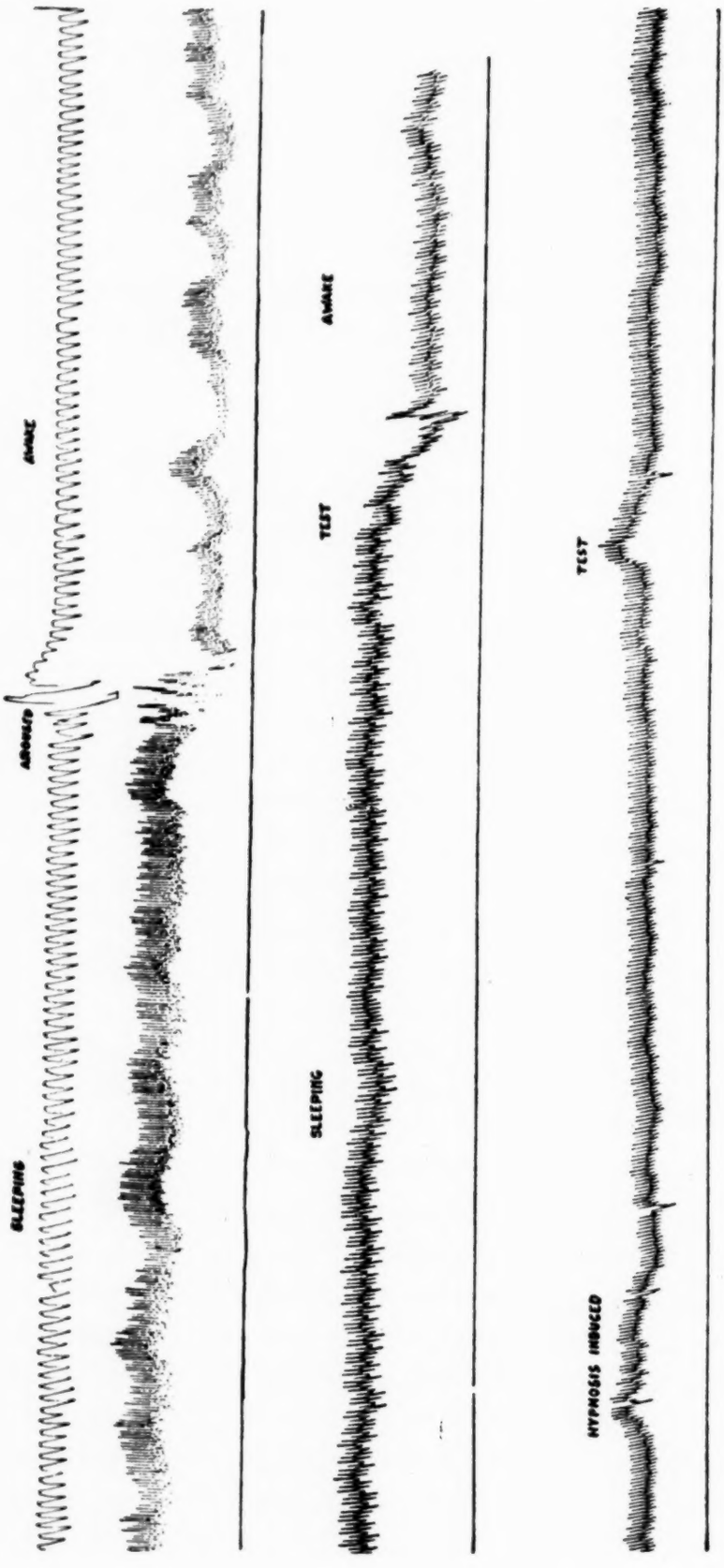
This is an excerpt from a typical hypnosis session in subject no. 4. It begins with the subject awake, then hypnosis was induced followed by suggestion for localized analgesia in one arm. The short brief reflex rise in volume near the center of the excerpt is where the test for analgesia was made by piercing the skin with a pin. The facial expression did not indicate any feeling of pain. When the non-analgesic arm is pierced, the reflex rise in volume is similar, but the facial expression and bodily movements indicate pain. In spite of lengthy records, hypnosis in this subject never merged into natural sleep.

Relationship of Results to Circulatory Theories

The so-called 'cerebral anæmia' theory of sleep is found untenable as an explanation of sleep in our subjects. On the contrary, rather than a condition of cerebral anæmia, our observations indicate that with the onset of sleep the volume of blood in the brain increases slightly with a more pronounced pulse.

Our data supports the findings of Shepard and Stevenson *et al.*, that cerebral congestion is an accompaniment of sleep, but it does not agree with the cerebral congestion theory

PLATE II


SLEEPING
AROUSED
AWAKE
SLEEPING
TEST
AWAKE
HYPNOSIS INDUCED
TEST

of sleep as postulated by Stevenson *et al.* We have shown that the circulatory changes do not precede the onset of sleep; and that the circulation changes are therefore more likely to be the result of, rather then because of, sleep. We have also shown that the subjects report being awake after arousal while the volume curve is still high, a condition that would be unlikely if sleep is to be explained by mere mechanical pulling apart of the neurones from the increased intracranial pressure.

Conclusions

Four young men and one young woman, having recovered from accidents that necessitated removal of a portion of the skull, acted as subjects in the observation of cerebral circulation during sleep. In two of these subjects a profound somnambulistic hypnotic trance was induced. From twenty observations upon induced hypnosis from these subjects and thirty-four records of sleep from all we summarize our results as follows:

The volume of blood in the brain increases during sleep with a more pronounced pulse, which we envisage as being due to relaxed blood vessels. The rise in volume is gradual and rhythmical until it reaches a maximum which is sustained at a fairly constant level during deep sleep.

On being awakened, the volume curve descends to a normal level, although at times there may be a short rise before the volume fall occurs. Accompanying the circulation changes are the slower heart rate and slight decrease of blood pressure in sleep.

An auditory stimulus which is insufficient to awaken the sleeping subject is likely to produce a diminution in the volume of the brain; whereas, the same auditory stimulus while awake is likely to produce a rise in volume.

With the onset of hypnotic sleep the changes of cerebral circulation did not appear. The cerebral circulation prevailing during hypnosis resembles the waking state rather than that of sleep. The pulse cannot be distinguished from a corresponding wake period in amplitude, form of pulse wave, or volume.

Howell's so-called 'cerebral anæmia' theory of sleep and

the 'cerebral congestion' theory of Stevenson, Christianson, Wortis, the author considers inadequate as an explanation of sleep in his subjects. There are changes in the cerebral circulation with the onset of sleep but these changes are more likely the result of sleep rather than the cause. This author believes that we must look elsewhere than in our present circulation theories for an explanation of sleep.

(Manuscript received July 10, 1938)

REFERENCES

1. Bayliss, W. M., Hill, L. E., and Gulland, G. L., On intracranial pressure and cerebral circulation, *J. Physiol.*, 1895, **18**, 334–362.
2. Blackenhorn, M. A., and Campbell, H. E., The effect of sleep on blood pressure, *Amer. J. Physiol.*, 1925, **74**, 115–120.
3. Brooks, H., and Carroll, J. H., A clinical study of the effects of sleep and rest on blood pressure, *Arch. Int. Med.*, 1912, **10**, 97–102.
4. Brush, C. E., and Fayerweather, R., Observations on the changes in blood pressure during normal sleep, *Amer. J. Physiol.*, 1901, **5**, 199–210.
5. Forbes, H. S., and Wolff, H. G., Cerebral circulation III. The vasomotor control of cerebral vessels, *Arch. Neurol. and Psychiat.*, 1928, **19**, 1057–1086.
6. Gibbs, F. A., Gibbs, E. L., and Lennox, W. G., Cerebral blood flow during sleep in man, *Brain*, 1935, **58**, 44–48.
7. Hill, L. E., *Physiology and pathology of the cerebral circulation.* London: J. and A. Churchill, 1896.
8. Howell, W. H., A contribution to the physiology of sleep based upon plethysmographic experiments, *J. Exper. Med.*, 1897, **2**, 313–345.
9. Howell, W. H., *Text Book of Physiology*, W. B. Saunders, 1936, 277.
10. Jenness, A., Wible, C. L. Respiration and heart action in sleep and hypnosis, *J. of Gen. Psychol.*, 1937, **16**, 197–222.
11. Landis, C., Changes in blood pressure during sleep as determined by the Erlanger method, *Amer. J. Physiol.*, 1925, **73**, 551–555.
12. Loomis, A. L., Harvey, E. N., and Hobart, G., Electrical potentials of the human brain, *J. Exper. Psychol.*, 1936, **19**, 249–279.
13. Mosso, A., *Über den Kreislauf des Blutes in Menschlichen Gehirn.* Leipzig, 1881.
14. Roy, C. S., and Sherrington, C. S., On the regulation of the blood supply of the brain, *J. Physiol.*, 1890, **11**, 85–108.
15. Shepard, J. F., *The circulation and sleep*, University of Michigan Studies, Scientific Series, vol. 1.
16. Stevenson, L., Christensen, B. E., and Wortis, S. B., Some experiments on intracranial pressure in man during sleep and under certain other conditions. The intracranial pressure in health and disease, *Proc. Ass. Res. Nerv. and Ment. Dis.*, Baltimore: Williams and Wilkins, 1929.
17. Talbot, G. A., Ready, F. L., and Kuhlman, F. W., Plethysmographic and pneumographic observations made in hypnosis, *Amer. J. Physiol.*, 1924, **68**, 113.
18. Tamburini, A., and Seppelli, G., Contribution de l'étude expérimentele de l'hypnotisme, *Arch. Ital. Biol.*, 1882, **2**, 273–277.
19. Walden, E. C., A plethysmographic study of the vascular conditions during hypnotic sleep, *Amer. J. Physiol.*, 1900–01, **4**, 124–161.

BRAIN POTENTIALS AND LATERAL DOMINANCE IN IDENTICAL TWINS [1, 2]

BY EDWARD T. RANEY

Brown University and Emma Pendleton Bradley Home

In a previous paper the author (**16**) has reported a study on reversed lateral dominance in a group of identical twins. It was shown that in the pattern of lateral dominance revealed by the phi-test, one twin is the mirrored counterpart of the other. Since a similar relationship was not found consistently in dominance patterns of handedness and eyedness, it was assumed that the phi-test reaction pattern might be an index of a genetically determined underlying tendency for a dominant laterality of function in the brain.

In the present study an attempt has been made to gain some insight into the nature of lateral dominance from records of brain potentials from the two hemispheres as recorded in the electro-encephalograms. Previous studies by Davis and Davis (**2**), and Loomis, Harvey and Hobart (**14**), of brain potentials as recorded from various parts of the head surface in identical twins have shown that the brain potentials of identical twins appear to be very similar. These investigators did not report any studies of the relative activity of the right and left hemispheres, so that this study was undertaken in order to relate any differences that might be found between the two hemispheres to behavioral indices of lateral dominance. It has already been noted by Jasper (**6**) that the brain potential records from homologous regions on the two sides of the head show only slight differences in normal subjects although great bilateral differences are found in pathological

[1] Abstract of thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Brown University, January, 1938.

[2] This study was made under the direction of Dr. Herbert Jasper whose aid I gratefully acknowledge. In addition I wish to thank Dr. R. D. Allen, Assistant Superintendent of Providence City Schools, for his aid in securing the twin subjects.

cases. If significant differences can be shown in electrical activity from the right and left homologous cortical regions, a careful analysis of their nature is important, especially with reference to the physiology of lateral dominance. In spite of several attempts to determine what is the underlying physiological basis of the dominance of one hemisphere over the other (12), there is as yet no definite knowledge as to its exact nature. It may be assumed that one hemisphere is more excitable or has a slightly higher metabolic rate than the other (3, 4, 7, 10). If this is so, these differences might well be reflected in electro-encephalographic records from the two hemispheres.

If a consistent relationship can be found between the electro-encephalograms from the two sides of the head and some centrally controlled behavioral index of lateral dominance, such as the phi-test, the differences found in the electro-encephalograms may be assumed to have significance in the mechanism for dominance in behavior. To find such a relationship between the brain potentials and some behavioral index would be especially important because these potentials are obtained directly from the normal brain without the attendant effects of ablations generally found in neuropathological studies.

Procedure

In a study of bilateral differences in electro-encephalograms, it is important that simultaneously independent records be obtained from the two sides of the head. In this study the amplifiers consisted of four completely independent four stage units, entirely push-pull in design to insure independent differential recordings from four pairs of electrodes, no electrode being directly grounded. Two microfarad condensers and 0.5 megohm grid resisters were used in the resistance-capacity coupling. A Westinghouse type PA, four element oscillograph with a natural frequency of 1,500 cycles was used in recording (8). Jasper (9), and Jasper and Andrews (8) have shown that, with these amplifiers, different frequencies and types of potential changes can be recorded independently from different regions of the brain.

The electrodes were small chlorided silver hats with felt-covered brims having an inside diameter of 5 mm. Each electrode was fixed to the head with collodion, the contact with the scalp being made through electrode jelly. The lead wires from the head to the amplifiers were about 3 feet (76.2 cm) in length.

The standard electrode placements used for recording from the central and occipital regions, including a diffuse lead from the ear as described by Jasper and Andrews (8), were used. Measurements for placement of pairs of electrodes along the median sagittal line were made to the transverse plane of the median electrode. The central

region lay in a line drawn from the mid-sagittal point to the center of the zygomatic arch; the occipital region lay between the lambda and the inion as indicated in Fig. 1. The inside separation of all pairs of electrodes equalled 20 mm. The median electrode on one side was separated from that of the homologous pair on the other side by a distance of 3 cm. The median electrodes were thus 15 mm on either side of the mid-line.

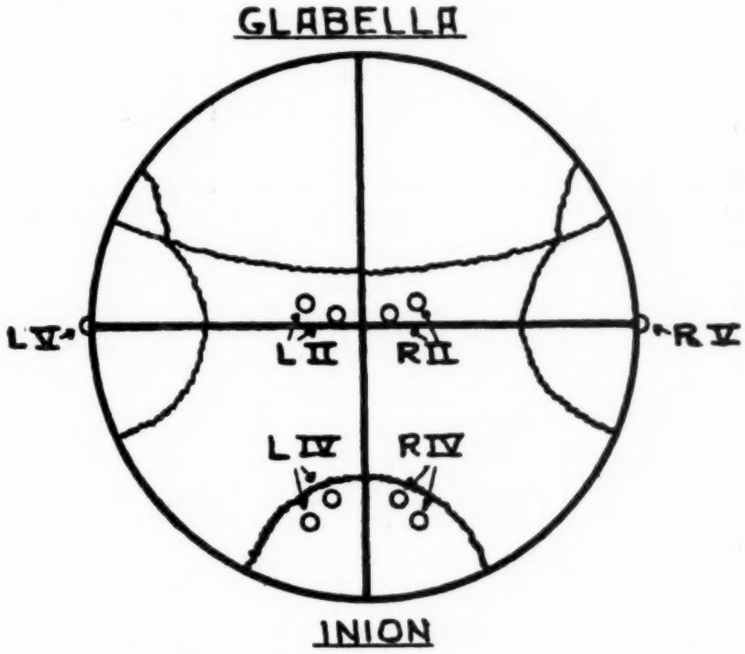


FIG. 1. L II and R II refer to electrode placements over pre-central area. L IV and R IV refer to electrode placements over occipital area. L V and R V refer to indifferent electrode placements behind the ear.

When taking the electro-encephalograms, the twin pairs were placed in a reclining position, side by side, in a sound resistant electrically shielded room. A sheet was placed between them to avoid direct contact of one twin with the other. The recording apparatus was in an adjoining shielded room, so that the subjects were undisturbed during the experiment. An observer sat in the room with the subjects to record any movements made by the subjects and to keep the subjects as quiet as possible during the taking of the records.

Four records were taken on each pair of twins. Each record included simultaneous recordings from the right and left sides of the head on each of the twins, for example, the right and left occipital regions from one twin simultaneously with the right and left occipital regions from the other twin. The first recording was from the central region, with bipolar electrodes. The second was from the occipital region with bipolar electrodes. The third record was from the central regions with a monopolar lead and a diffuse electrode placed on the ear. The fourth record was from the occipital regions with a monopolar lead and a diffuse electrode placed on the ear. The monopolar lead was taken to check the possibility of interference artifacts from bipolar recordings.

The most prominent feature of electro-encephalograms is that of the alpha rhythm of about 10 cycles per second. The quantification of this activity has been shown by Davis and Davis (2) to be of importance in interpretation of brain potentials occurring

TABLE I

Serial Number of Twin-Pair	Percentage of Alpha Activity				Amplitude of Alpha Activity				Frequency of Alpha Rhythm	
	Occipital		Central		Occiput		Central			
	left	right	left	right	left	right	left	right	left	right
1 B	.96	.96	.33	.46	35	41	10	13	9.9	9.8
A	.95	.97	.43	.38	69	38	23	14	9.7	9.7
2 B	.99	.94	.20	.36	44	41	14	32	11.0	11.0
A	.97	.94	.25	.30	18	27	10	9	10.9	10.9
3 A	.97	.95	.72	.87	43	36	34	23	8.8	9.2
B	.86	.92	.92	.82	30	38	25	30	9.3	8.9
4 A	.96	.94	.22	.14	61	50	15	10	9.3	9.2
B	.84	.91	.11	.14	40	54	12	13	9.9	9.7
5 A	.71	.77	.79	.67	54	66	48	48	9.0	8.9
B	.84	.84	.84	.77	57	48	50	58	8.5	8.6
6 A	.85	.96	.69	.89	11	15	8	12	9.2	9.2
B	.89	.92	.91	.87	19	17	14	13	9.3	9.3
7 A	.96	.98	*.47	.66	39	45	16	20	9.4	9.4
B	.92	.92	*.80	.77	30	32	41	39	9.4	9.6
8 A	.84	.60	.26	.29	*32	36	52	64	8.5	8.4
B	.82	.87	.30	.15	*50	39	60	58	8.9	8.9
9 A	.81	.87	.89	.82	60	50	28	40	9.7	9.8
B	.77	.84	.81	.85	51	61	29	22	9.9	9.8
10 A	.87	.92	.94	.89	46	53	60	59	9.6	9.5
B	.94	.93	.78	.93	40	51	26	52	8.9	8.2
11 B	.91	.84	.10	.18	38	32	31	22	8.7	8.6
A	.92	.93	.32	.36	39	38	14	15	8.4	8.4
12 B	.89	.93	.73	.81	46	34	28	34	10.5	10.3
A	.36	.22	.86	.80	35	20	25	25	11.1	10.6
13 B	.91	.89	.11	.15	12	17	14	14	9.4	9.0
A	.82	.90	.27	.20	20	18	17	11	9.0	8.8
14 B	.93	.95	.92	.92	28	23	65	45	Records not taken simultaneously	
A	.96	.93	.91	.88	39	40	46	55		
15 B	.95	.95	.63	.75	18	23	4	10	9.1	9.1
A	.95	.95	.69	.48	46	25	18	11	9.3	9.4
16 A	.94	.95	.90	.92	22	29	18	15	9.2	9.0
B	.91	.92	.45	.39	19	15	14	18	10.0	10.0
17 A	.86	.79	.15	.24	31	11	11	14	9.7	9.9
B	.79	.90	.15	.12	23	23	17	11	9.8	9.6
Average	.88	.88	.56	.56	.35	.35	.27	.27		

The first twin record in each pair is the right dominant twin, according to the phi-test.

* These data taken from recordings with monopolar lead.

at regular intervals at frequencies between 7.5 and 15 per second. Due to the sensitivity of the apparatus and its noise level (less than 2 micro-volts) only alpha waves of greater than 4 or 5 micro-volts were considered.

The electro-encephalograms were analyzed in the following manner:

1. *Percentage of Alpha Activity.*—In each record the number of millimeters during which there was a definite indication of alpha activity was measured and compared with the total length of the record. This reading gives a direct measurement of the relative amount or percentage of alpha activity shown by an individual during the tested period.

2. *Frequency of Alpha Rhythm.*—For each record the average frequency of the alpha rhythm was determined by measurement of the average period in regular sequences of 5 waves each, taking 20 representative samples.

3. *Amplitude of Alpha Activity.*—A measure of the general level of the amplitude of the alpha waves was obtained by taking a typical series containing at least 10 regular waves. The average amplitude in millimeters was then converted into micro-volts according to the calibration for the sensitivity of the amplifiers taken at the end of each record.

Perhaps the best measure of the amount of alpha activity is that which includes both amplitude and the number of alpha waves in a given time (amplitude squared times amount) (1). However, in examining the raw data presented in Table I it is apparent that, in this determination, the influence of the amplitude measurements is so great that the results based on amplitude alone would indicate essentially the same tendency toward bilateral differences as that indicated by the measurement which includes amount of activity as well as amplitude. This is a good indication that amplitude measurements are as important in describing the differences between electro-encephalograms as the percentages of alpha activity. If we assume that amplitude is a function of the number of cortical cells synchronized in a given potential (7), amplitude becomes of additional significance in the quantification of this type of cortical activity.

In the present study all amplitude and percentage of alpha activity readings were regarded as having a 5 percent error. This percentage error was estimated from the product of probable errors in recording techniques and in the reading of the record. Thus comparative differences of less than 5 percent were considered insignificant. In addition to the above quantitative measurements, qualitative differences and similarities have been considered.

The subjects were the same 17 pairs of identical twins used in the author's study of reversed lateral dominance (16). These subjects have been given the following tests of dominance: (1) questionnaire of handedness habits, (2) ocular dominance (paper sighting), (3) Van Riper critical angle board, (4) phi-test of lateral dominance in visual perception.

Results

Similarities of Twins.—Figure 2 presents qualitative evidence that twins may have very similar patterns of brain potentials. Three examples are given. In the first example there is a large amount of alpha activity from both sides of the head from both twins. In the second example there is a great amount of beta (a frequency between 16 and 30) from

both twins. In the third example there are very few regular potential changes from either side of the head from either twin. These three examples illustrate that the type of potential pattern found in one twin will probably appear in the other.

The data of the electro-encephalograms when quantified also show that electro-encephalograms of identical twins may be more similar than the electro-encephalograms of unrelated children. In comparing twins the data from the two sides of the head were averaged in order to make the results comparable to the results of Davis and Davis (**2**), and Loomis, Harvey and Hobart (**14**). These investigators reported that identical twins had similar electro-encephalograms. These two studies reported results from only two and nine sets of twins respectively, which may account to some degree for the discrepancies between their findings and the findings in this study.

Some discrepancies may also be attributed to the difference in methods used to analyze the data. Davis and Davis used four categories of classification. Category I, 0%–25%, Category II, 26%–50%, Category III, 51%–75%, and Category IV, 76%–100%. These figures represent the percentage of time in a given sample of record during which alpha activity was present. If this classification were used in the present study, 82 percent of the twin pairs would have similar patterns. However, if the subjects were grouped by chance, a degree of similarity of at least 77 percent would still be obtained, due to the fact that 30 of the 34 individuals in the study would fall in Category IV.

In order to find whether a significant difference could be obtained, the data in the present study were compared in terms of Spearman's rank method of correlation. These correlations are as follows: Percentage of activity, occipital region: .61 ± .108; central region: .87 ± .042; Amplitude of activity, occipital region: .66 ± .096; central region: .76 ± .072; Frequency: .91 ± .029. From these correlations it is apparent that in a group of identical twins there is a greater degree of similarity between the electro-encephalograms with respect to frequency, percentage and amplitude of alpha waves

of twin pairs than there is between pairs of individuals of a similar age range chosen at random.

The similarity of twins is more apparent in the records of the amount of alpha activity found in the central region, due apparently to the fact that in this study there are greater

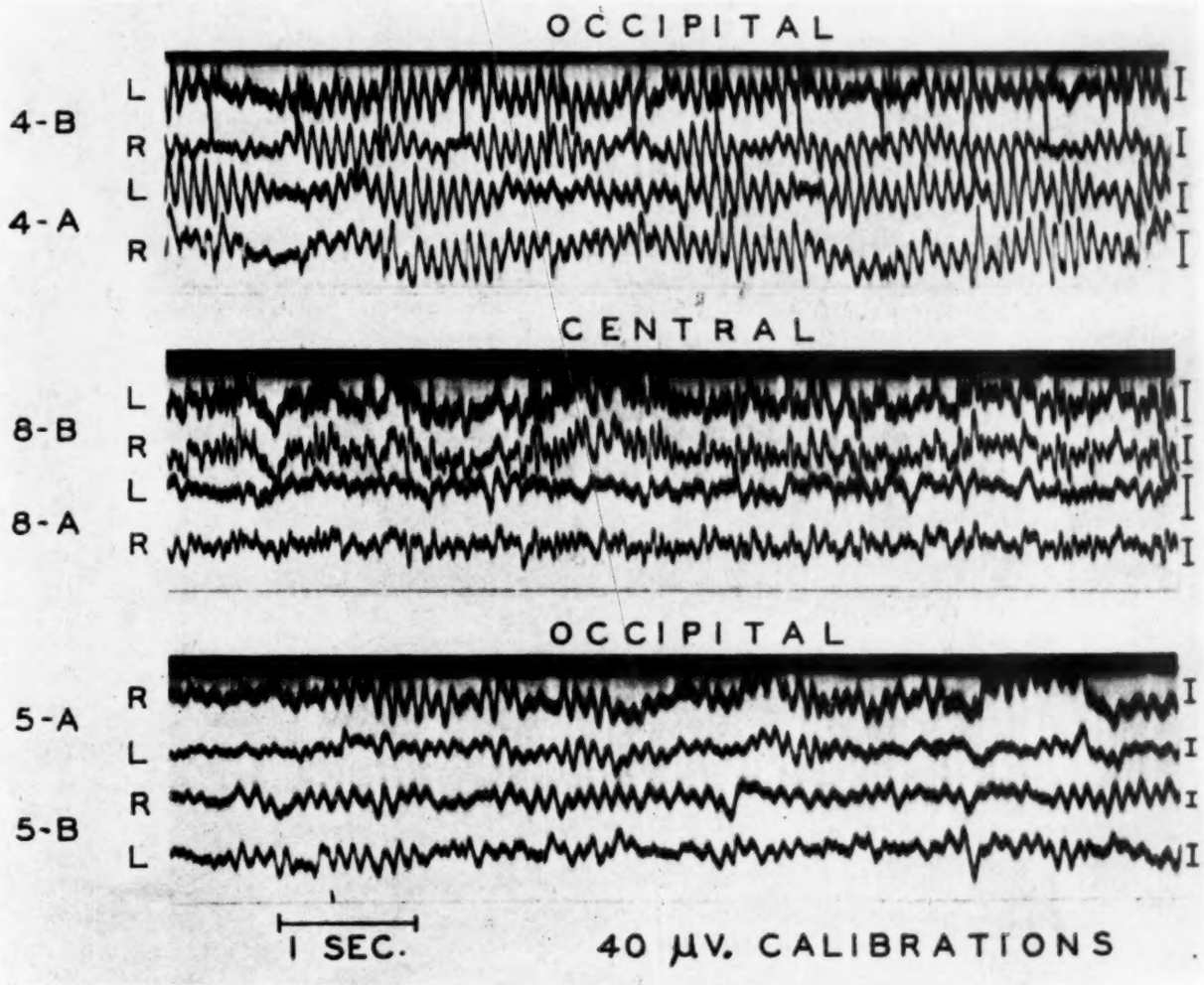


FIG. 2. Similarity of electro-encephalographic patterns in identical twins. Records from three pairs of twins, the potentials having been recorded simultaneously from both members of each pair.—*A* refers to the right-handed and *B* to the left-handed member. L and R represent the records from the left and right sides of the head. The brain regions are indicated above each record. Bipolar recording. For further explanation see text (p. 23).

individual differences in the recordings from that area. In the recording from the occipital region, records from all individuals are so much alike that in order for twin pairs to be more alike than non-twin pairs, it is necessary for them to be practically identical.

This similarity in percentage and amplitude cannot be attributed to the influence of the factor of age since the range of the correlations between age and percentage and age and amplitude of alpha activity is from .02 to .29. Frequency, however, has been shown to be positively related to age by Lindsley (13), and the present study has corroborated this relationship. The correlation of frequency with age is .73. When the high correlation of .91 is corrected for this age factor, it is reduced to .83 which indicates that the similarity

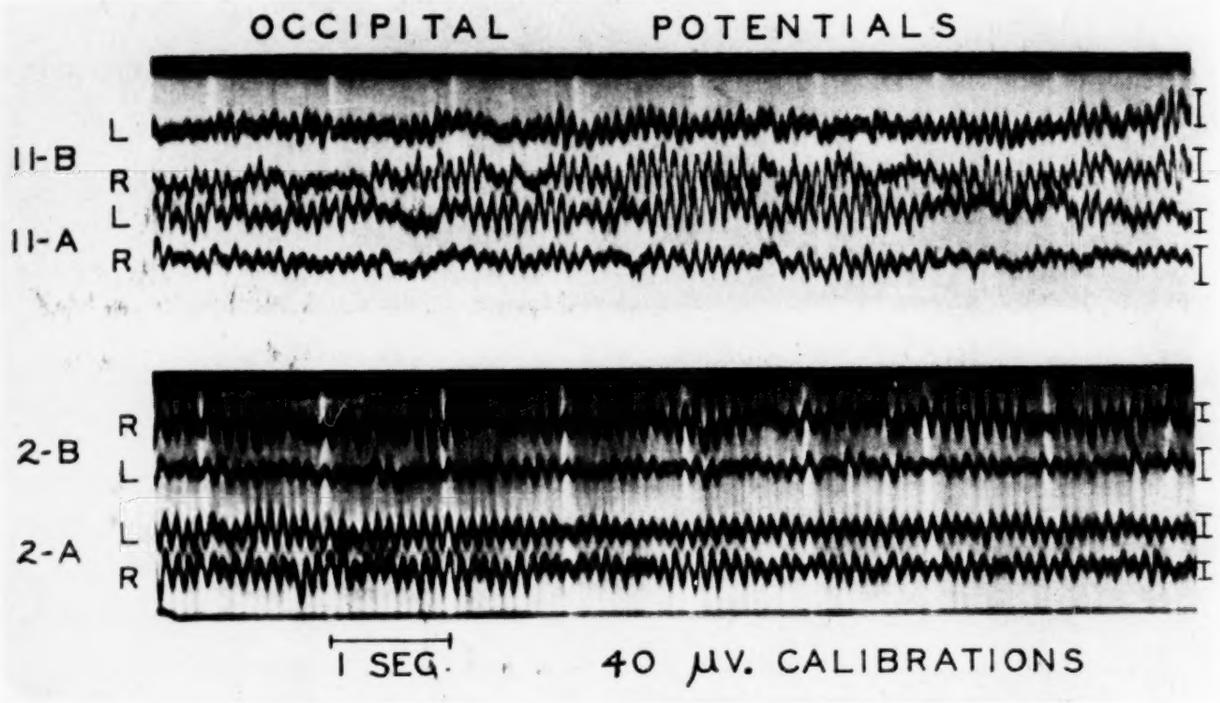


FIG. 3. Differences between the electro-encephalographic patterns in identical twins. Records from two pairs of twins, recording and lettering as for Fig. 3. The pattern recorded from the left-handed member (*B*) of pair 2 appears to be more nearly similar to that of both members of pair 1 than to that of his twin (2*A*). For further explanation see text (p. 23).

between twins in frequency of alpha rhythms is no higher than that similarity which is found in percentage and amplitude of alpha activity.

Differences of Twins.—Correlations of .60 to .80 cannot, however, be considered as showing that "identical twins have identical brain waves" since a great deal of independence is also shown by these coefficients. In exceptional cases the

differences in a twin pair may be as great or greater than differences between unrelated children (Fig. 3). Even in cases where the records of the twin pairs appear similar, a more detailed analysis indicates significant differences between twins.

The difference between one twin and his pair is noticeable in the data in Table II. To obtain the data in this table one

TABLE II

COMPARISON OF TWIN PAIRS IN TERMS OF RELATIVE DEGREE OF ACTIVITY ON THE TWO SIDES OF THE HEAD

	Percentage of Activity		Amplitude of Activity	
	Occipital	Central	Occipital	Central
Average relative degree of activity of members of twin pair with smallest relative difference between the two sides of the head	.97 ±.006	.89±.018	.87 ±.018	.88±.025
Average for members of twin pair with largest relative differences	.906±.023	.79±.034	.695±.033	.65±.032
Critical ratio	2.6	2.6	5.1	5.7

twin of each pair was placed in a group, depending on the size of the difference between the two hemispheres. The twin of the pair with the smallest relative difference between the two hemispheres was placed in one group, and the twin of the pair with the largest relative difference between the two hemispheres was placed in the other group. It is apparent that there is a definite tendency for one twin of a pair to have a significantly larger relative difference between the two sides of the head, especially in amplitude measurements. Frequency measurements were not included in the comparison since the differences between the two sides of the head were so small as to be insignificant. The range of differences was from 0 to .9 with 59 percent of the individuals showing a difference of .1 or less.

Only when treated as a group do identical twins show a greater similarity in electro-encephalograms than unrelated individuals. In individual instances, the difference between

the twins may be greater than those of non-twins. Moreover the identical twins differ in that there is a statistically significant tendency for the bilateral differences found in one twin to be greater than those in the other twin of the pair.

Reversed Bilateral Asymmetry in the Electro-encephalograms as Related to Behavioral Indices of Lateral Dominance.—Table III gives a further indication that identical twins are not alike

TABLE III

COMPARATIVE DIFFERENCES OF THE TWO SIDES OF THE HEAD IN TWIN PAIRS

	Percentage of Activity		Amplitude of Activity	
	Occipital	Central	Occipital	Central
Greater on right side in one twin, and left side in other	18%	65%	65%	76%
Greater on right side in one twin, no difference in other	35%	6%	0	18%
Greater on left side in one twin, no difference in other	18%	12%	18%	6%
Greater on right side in both twins	6%	6%	12%	0
Greater on left side in both twins	0	6%	6%	0
No difference in either twin	29%	6%	0	0

since there is a tendency for identical twins to show a reversed bilateral asymmetry in the electro-encephalograms. 88 percent of the individuals in this study had clear bilateral differences in the amplitude of the central area. In 76 percent of the twin pairs there was a contralateral correspondence in these bilateral differences. In the remaining percentage of twin pairs, one twin of a pair did not show clear bilateral differences.

In the amplitude from the occipital region, 91 percent of the individuals showed clear bilateral differences, and 65 percent of the twin pairs showed a contralateral asymmetry in these differences. In only 18 percent of the twin pairs, the bilateral differences were on the same side of the head in both twins of the pair.

There is a tendency for the reversed laterality in the electro-encephalograms to be similar to that found in the behavioral indices of lateral dominance (Table IV). When

TABLE IV

RELATIONSHIP BETWEEN LATERAL DOMINANCE IN BEHAVIOR AND THE RELATIVE AMOUNT OF ALPHA ACTIVITY FROM THE RIGHT AND LEFT HEMISPHERES

	Percentage of Activity								Amplitude of Activity							
	Occipital				Central				Occipital				Central			
	Phi-test	Handedness	Critical Angle	Reversed on All Three Tests	Phi-test	Handedness	Critical Angle	Reversed on All Three Tests	Phi-test	Handedness	Critical Angle	Reversed on All Three Tests	Phi-test	Handedness	Critical Angle	Reversed on All Three Tests
No. of cases	17	9	9	6	17	9	9	6	17	9	9	6	17	9	9	6
Greater on non-dominant side in both twins	0	22%	12%	0	47%	66%	88%	100%	47%	66%	66%	84%	41%	55%	44%	50%
Greater on non-dominant side in one of a twin pair	23%	0	22%	34%	18%	22%	0	0	0	0	0	0	18%	22%	22%	33%
Greater on dominant side in both twins	12%	12%	12%	0	18%	12%	0	0	18%	11%	0	0	35%	22%	12%	11%
Greater on dominant side in one twin	29%	33%	0	16%	0	0	0	0	18%	4%	0	0	6%	0	22%	0
Greater on left side in both twins	0	0	0	0	6%	0	12%	0	6%	11%	11%	16%	0	0	0	0
Greater on right side in both twins	6%	0	12%	0	6%	0	0	0	12%	0	22%	0	0	0	0	0
No significant bilateral difference	29%	33%	0	50%	6%	0	0	0	0	0	0	0	0	0	0	0

lateral dominance is determined by the phi-test, it is to be noted that in 47 percent of the twin pairs, both twins of a pair showed a greater percentage of alpha activity on the non-dominant side of the head in the central area. When those twin pairs are included in which only one twin of a pair gave indication of a bilateral difference in brain potentials, the percentage is increased to 65 percent. This is clearly above a chance relationship which would be expected to be 25 percent under these circumstances. In the amplitude measurements no clear relationship is apparent when the phi-test is used as the criterion of dominance.

When some indications of reversed laterality were found on the handedness tests or on the critical angle board, a relationship between lateral dominance and bilateral differences in the alpha activity is found in the amplitude measurements from both the occipital and central areas, and in the percentage of activity from the central areas. The range of percentages of those twin pairs showing alpha activity of greater percentage or amplitude on the non-dominant side of the head is from 44 to 88 percent, which percentages are clearly above chance relationship. When those twin pairs are included in which only one twin of a pair gave evidence for bilateral difference in alpha activity the range of percentages is from 66 percent to 88 percent.

If the twin pairs showed a reversed laterality on the phi-test, the handedness test, and the critical angle board, the above percentages are more clearly demonstrated and exaggerated. In the percentage of activity from the central region, 100 percent of the twin pairs showing reversed laterality on the three tests gave a reversed bilateral asymmetry in the electro-encephalograms. In all cases there was a greater amount of activity on the non-dominant side of the head. In amplitude measurements from the occipital region 84 percent of the twin pairs who met the criterion of reversed laterality on the three behavioral indices had a greater amount of activity on the non-dominance side of the head. Similarly, in the central region, 83 percent of the twin pairs who had reversed laterality on the three behavioral indices has a greater amount of activity on the non-dominance side of the head.

The bilateral differences are more pronounced in these twin pairs highly selected for dominance than in the group as a whole, especially in the amplitude measurements. For this analysis it is necessary to compare the data from the two sides of the head in terms of degree of difference, that is, 100 percent would indicate that the amplitude or percentage is the same for both sides of the head; 50 percent would indicate that the amplitude and percentage of the right side of the head is only half the amplitude and percentage on the left side of the head; minus 50 percent would indicate that the amplitude and percentage on the left side of the head is only half of the amplitude and percentage on the right side.

In the occipital region in the left dominant group according to the phi-test the average degree of difference between the two sides of the head is − 72 percent for the six selected cases and − 93 percent for all the cases (17 individuals). In the right dominant group, the average degree of difference is 85 percent for the selected cases and 98 percent for the right dominant group. For the central region in the left dominant group, the average degree of difference for the selected cases is − 84 percent as compared to − 96 percent; for the right dominant group 80 percent as compared to 92 percent. In the percentage of activity in the occipital region there is no difference between the group as a whole and the highly selected twins, but in the central region in the left dominant group the degree of difference for the selected cases is − 85 percent as compared to − 97 percent; in the right dominant group 83 percent as compared to 87 percent. These averages indicate that greater differences are to be found between the two sides of the head in cases highly selected for dominance.

While the differences between these averages are not significant statistically, due to the small number of cases, they do indicate that there is a definite tendency for bilateral differences in the electro-encephalograms to be more apparent in individuals in which lateral dominance is very pronounced.

There is, then, a slight relationship between lateral dominance as tested by the behavioral indices and the bilateral differences shown in the electro-encephalograms. This rela-

tionship is expressed in a greater percentage and amplitude of alpha activity on the non-dominant side of the head. When the cases are selected for consistency of lateral dominance in behavior, this tendency becomes very clear and unquestionably significant.

There are indications that lateral dominance is a localized specific function of a given area rather than a completely uni-lateral gradient involving the entire cortical hemisphere, since there is no relationship between the bilateral differences found in the central region and those found in the occipital region. Even those cases highly selected for lateral dominance may show a reversal between the central and occipital regions in the contralateral correspondence found in the twin pair. Another indication that lateral dominance is not a consistent unilateral gradient can be noted in the records when they are examined minutely. It can be seen that the amplitude and percentage of activity on one side of the head are not always greater than the amplitude and percentage on the other side of the head, but from time to time first one side of the head and then the other has a greater amount of alpha activity. In a longer period of time, however, one side tends to dominate more of the time.

Relative Differences Between the Two Sides of the Head in the Right Dominant and Left Dominant Group.—It has already been noted in Table II that there is a definite tendency for one twin to have a significantly larger relative difference between the two sides of the head. In 71 percent of the twin pairs, the left dominant twin is the one with the smaller relative difference between the two sides of the head in the potentials from the central region. Considering the amplitude of the potentials from the central region, in 65 percent of the twin pairs the left dominant twin is the one with the smaller relative difference between the two sides of the head. The percentage of left dominant individuals showing a smaller difference between the two sides in the potentials from the occipital region is not significant.

Discussion

In a previous paper the author has pointed out that in some important respects identical twins are not identical (**16**). In the aspect of lateral dominance tested by the phi-test, one twin is the mirrored counterpart of the other. In the present study, we have further evidence that identical twins are not identical. There is a distinct tendency for the electro-encephalograms of one twin to show bilateral differences which are the reverse of those found in the electro-encephalograms of the other. Also, there is a definite tendency for one twin to have a significantly larger relative difference between the two sides of the head.

Upon examining the electro-encephalograms, it is evident that there are significant differences in the electrical activity of homologous regions of the right and left hemispheres. While the actual differences between the two hemispheres are not always large, it is thought that they are real, since bilateral differences greater than 5 percent were found in 88 percent of the 34 subjects in the recordings from the central area, and in 91 percent of the 34 subjects in the recordings from the occipital area.

There is apparently no relationship between the bilateral differences found in the central area and those found in the occipital area. Thus it appears that bilateral differences in brain potentials from the two sides of the head are a more localized specific function of a given area rather than a completely unilateral gradient involving the entire cortical hemisphere. This finding is in keeping with the physiological studies involving lesions or depression of activity in specific regions of the contralateral hemisphere in relation to lateral paw preference and electrical excitability patterns of peripheral nerves in the rat (**15**, **12**). These studies have indicated that while specific functions may be localized in a given area, the cortical control of lateral dominance related to one function may be independent from that concerned with another.

There is a relationship between lateral dominance in behavior and the bilateral differences found in the electro-

encephalograms, which is expressed as a tendency for there to be a greater percentage and amplitude of alpha activity on the non-dominant side of the head. In individuals highly selected for dominance the bilateral differences are emphasized.

The hypothesis has been advanced by Jasper (**7**, **10**), that a major factor in the control of the frequency, regularity, and amplitude of the bio-electric rhythms from the cortical neurones is the 'cortical excitatory state.' The reaction of a given cortical area to excitation through external sense fields is usually characterized by depression of the alpha rhythm. Consequently, a lesser amount of alpha rhythm might well indicate a higher level of excitation. Assuming that this hypothesis and its implications are true, it follows then that the amount of alpha activity present is an indication of the level of excitation of a given cortical area. It would appear then, since more alpha activity has been found on the non-dominant side of the head that the non-dominant cortex is less activated or less excitable, and that lateral dominance may be related to a cortical excitatory state.

The interpretation of lateral dominance as related to cortical excitatory state is in keeping with Jasper's (**5**), Jasper & Bonvallet's (**11**), and Peterson's (**15**) findings that lateral dominance is manifested in ratios of peripheral nerve excitability, and that these ratios are dependent upon the relative degree of activity of the right and left hemispheres.

A further relationship between level of cortical activation and lateral dominance is found in the tendency for the electroencephalograms of the two sides of the head to be more nearly alike in the left dominant twin, and in individuals who do not express strong lateral dominance than in individuals who do show strong lateral dominance. The individuals who do show strong lateral dominance tend to have a pronounced differentiation in excitatory state between the two sides of the head. The implication of this fact is that the amount of differentiation between the two hemispheres is greater when strong lateral dominance exists. Since the right dominant twin tends to have stronger lateral dominance

than the left dominant twin, the differentiation between the two hemispheres in the right dominant twin is greater. This is due probably to the fact that the right dominant twin is living in a right handed world, so environmental factors are favorable to the development of his lateral dominance habits. On the other hand, the left handed individual is inclined to be handicapped by this same factor, so that the left dominant twins' natural tendency for left dominance is curbed, and as a result the degree of differentiation between the two sides is not as great as that found in the right dominant twin.

If it is true that the differentiation between the two hemispheres is a function of lateral dominance in that the left dominant twin, or the individual without strong lateral dominance, tends to have a lesser degree of differentiation between the two hemispheres, there is evidence for an association of lateral dominance with the higher forms of neural integration. The differences between the cortical excitatory states in these individuals may be so small that the balance between the two hemispheres is very easily upset. On the other hand, in the individual with strong dominance the difference between the excitatory states may be so pronounced that one hemisphere may dominate the other, giving more stability to bilateral neural organization. This may be related to the fact that there is such a large percentage of left or mixed dominance among the mentally deficient, psychotic or psychopathic individuals (**12**).

It should be noted that the quantitative data on bilateral differences in the brain potentials refer to the relative differences between the two hemispheres over a period of time. Inspection of the records indicates, however, that the amplitude on one side of the head is not always larger than the amplitude on the other side of the head, but from time to time first one and then the other hemisphere has the larger amplitude. This may be related to the findings on the bimanual test in which a definite tendency to lead with one hand consistently is not found in most individuals. The most common tendency is for the individual to lead first with one and then with the other hand (**12**). If one assumes that

the bi-manual preference indicates some basic laterality of function, it may be concluded that a definite unilateral dominance does not exist, but that first one hemisphere and then the other may dominate, but with one dominating more of the time.

Summary

The data on bilateral differences in electro-encephalograms of identical twins indicate that identical twins are more similar than unrelated children only when treated as a group. The recorded potentials of identical twins may differ in that there is a tendency for one twin to show bilateral differences which are the reverse of those found in the other twin. Also, in most cases, one twin of the pair shows a significantly larger bilateral difference between right and left homologous brain areas. There is a tendency for the non-dominant side of the head according to behavioral indices to have a greater amount and amplitude of alpha activity in the electro-encephalogram.

(Manuscript received July 17, 1938)

REFERENCES

1. Cruikshank, R. M., Human occipital brain potentials as affected by intensity-duration variables of visual stimulation, *J. Exper. Psychol.*, 1937, **21**, 625–641.
2. Davis, H., and Davis, P., Action potentials of the brain of normal persons and in normal states of cerebral activity, *Arch. Neurol. & Psychiat.*, 1936, **36**, 249–279.
3. Gerrard, R. W., Factors controlling brain potentials, Cold Spring Harbor Symposium, *Quant. Biol.*, 1936, **4**, 292–304.
4. Hoagland, H., Some pacemaker aspects of rhythmic activity in the nervous system, Cold Spring Harbor Symposium, *Quant. Biol.*, 1936, **4**, 267–284.
5. Jasper, H. H., The effect of an induced bilateral metabolic gradient in the cerebral hemispheres upon excitability patterns in peripheral nerves in relation to right and left handedness in the rat, *Psychol. Bull.*, 1934, **31**, 635–636.
6. Jasper, H. H., Electrical signs of cortical activity, *Psychol. Bull.*, 1937, **34**, 411–481.
7. Jasper, H. H., Cortical excitatory state and synchronism in the control of bio-electric autonomous rhythms, Cold Spring Harbor Symposium, *Quant. Biol.*, 1936, **4**, 320–338.
8. Jasper, H. H., and Andrews, H. L., Electro-encephalography, *Arch. of Neur. & Psychiat.*, 1938, **1**, 96–115.
9. Jasper, H. H., Localized analyses of the function of the human brain by the electroencephalogram, *Arch. Neurol. & Psychiat.*, 1936, **36**, 1131–1134.
10. Jasper, H. H., Cortical excitatory state and variability in human brain rhythms, *Science*, 1936, **83**, 259–260.

11. JASPER, H. H., AND BONVALLET, N., Rôle de l'écorce dans l'organization asymétrique des chronaxies des nerfs symétriques chez les droitiers ou gauchers, *C.r. Soc. Biol.*, 1934, **117**, 991–994.
12. JASPER, H. H., AND RANEY, E. T., The physiology of lateral cerebral dominance, *Psychol. Bull.*, 1937, **34**, No. 194, 72–174.
13. LINDSLEY, D. B., Brain potentials in children and adults, *Science*, 1936, **84**, 354.
14. LOOMIS, A. L., HARVEY, E. N., AND HOBART, G., Electrical potentials of the human brain, *J. Exper. Psychol.*, 1936, **19**, 249–279.
15. PETERSON, G. M., Mechanisms of handedness in the rat, *Comp. Psychol. Monog.*, 1934, **9**, No. 6. Pp. 67.
16. RANEY, E. T., Reversed lateral dominance in identical twins, *J. Exper. Psychol.*, 1938, **23**, 304–312.

A QUANTITATIVE COMPARISON OF THE ELECTRICAL AND PHOTOGRAPHIC TECHNIQUES OF EYE-MOVEMENT RECORDING

BY A. C. HOFFMAN
University of Rochester
B. WELLMAN
Tufts College
AND
L. CARMICHAEL
Tufts College

The importance of the quantitative measurement of eye-movements for the solution of a whole series of problems in pure and applied psychology is an accepted fact. Electrical methods for the recording of eye-movements have recently been added to the other techniques which have been used in this field of study. The present paper reports a quantitative comparison of the results secured by the standard corneal reflection technique and one form of the new electrical techniques which have been developed for eye-movement study.

Schott (**6**); Meyers (**4**); Jacobsen (**2**, **3**); Mowrer, Ruch and Miller (**5**); Fenn and Hursh (**1**); and others have studied the electrical changes produced by the movements of the eyes in their orbits. It is now generally agreed that the potential changes produced by the eye-movements depend upon the fact that there exists a potential difference between the cornea and the retina of the living eye. This is shown in most schematic form in Fig. 1. Electrodes can be attached on the skin and at any position about the orbits. As the eyes move, potential differences are set up which can be led off from the electrodes just mentioned. When the potentials so secured have been suitably amplified, they may be recorded by a suitable galvanometer or oscillograph.

In the present experiment, constant conditions were

arranged which were as typical as possible of the conditions usually existing when eye-movements are to be measured in psychology. Apparatus was then assembled and constructed which made possible the simultaneous recording and measure-

FIG. 1. Schematic diagram of polarity of the two eyes with indication of two electrodes as placed on the skin near the orbits.

ment of the movements of the eyes through predetermined excursions by both photographic and electrical means. Specifically, then, in this study we have compared quantitative relationships between the voltages produced by eye-movements and the extent of such movements as recorded on film simultaneously, using a binocular, corneal reflection photographic technique.

The changes in the corneo-retinal potentials were recorded on moving paper, using amplifiers and a Westinghouse type PA mirror oscillograph. Electrodes were constructed which could be instantaneously attached to the skin about the eye balls by little circles cut from adhesive plaster. These electrodes were made of flat solder drops about 4 mm in diameter to which were attached flexible leads. Figure 2 shows a diagram of one of these electrodes. Before applying the electrode, the skin at the place of application was gently massaged with a small amount of Cambridge Instrument Company Electrode Jelly. The amplifiers were of a paired non-interfering, resistance-capacity coupled type. They were thus especially adapted for recording the absolute magnitude of potential shifts. Their construction, of course, does not make it possible for them to record maintained potentials. For this latter purpose, a direct coupled amplifying system of some sort would naturally have to be employed.

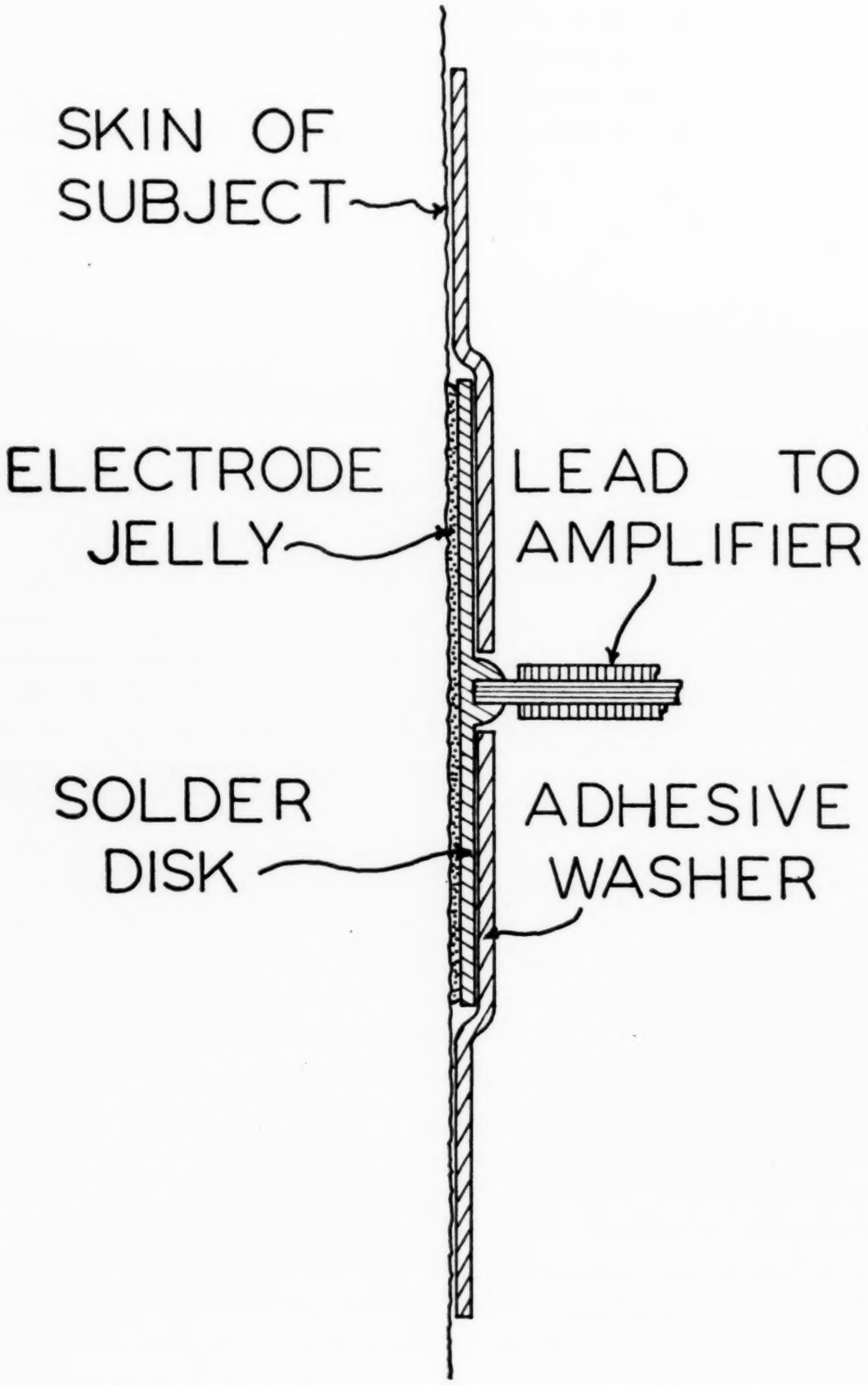


FIG. 2. Diagram of an electrode of the type used in this study.

In each of the present experiments here reported, four electrodes of the sort just described were fastened about the orbit of each eye. We have designated these placements by the subjacent ocular muscles. These names were used entirely for convenience because it is now agreed that electrical changes of the sort studied in this experiment are independent of the action potentials of the extrinsic eye muscles. The electrical placements are thus referred to as: left external, left internal, left superior, and left inferior. The same designation is used for the right eye. All of the eight electrodes were used in each experiment reported here, although only four were

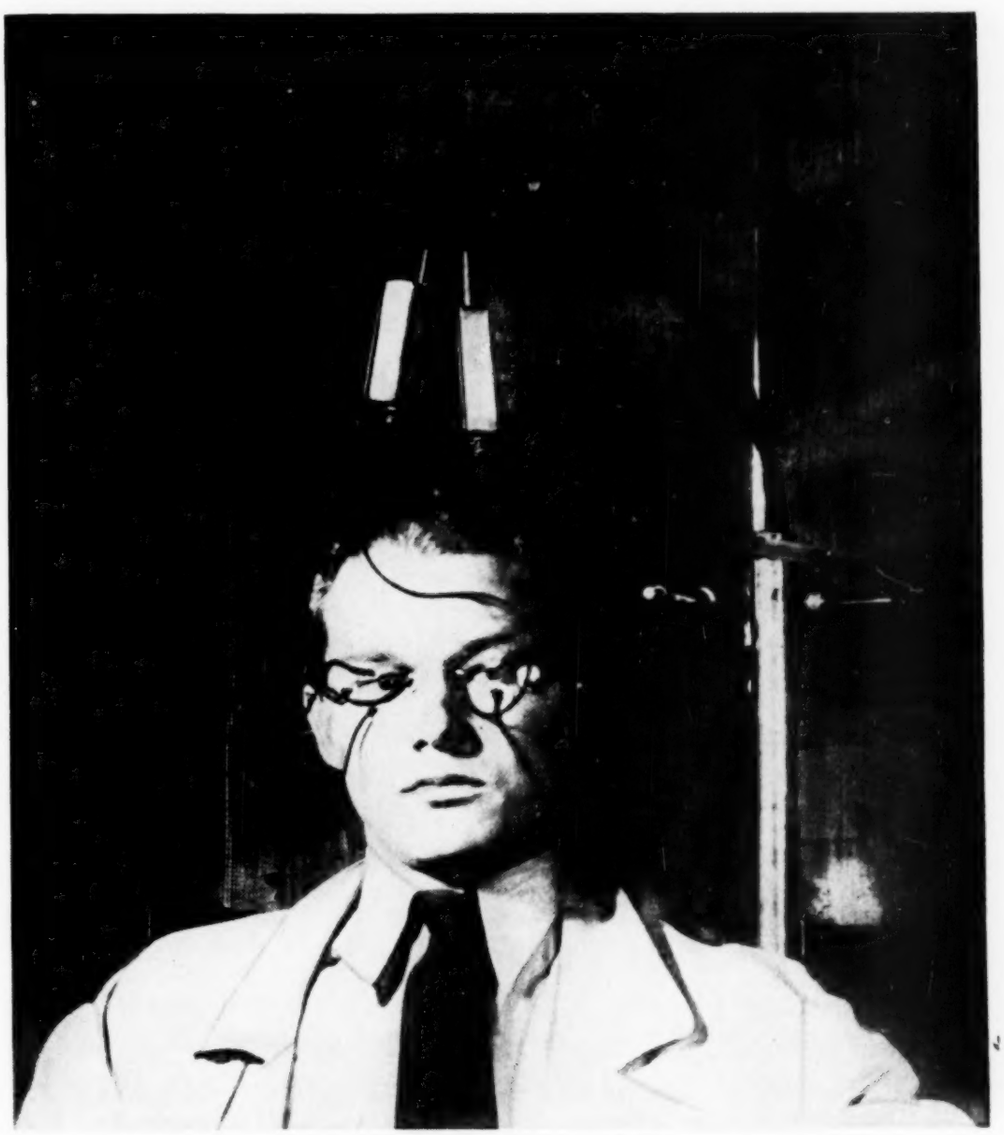


FIG. 3*A*. Front view showing a subject with electrodes in place.

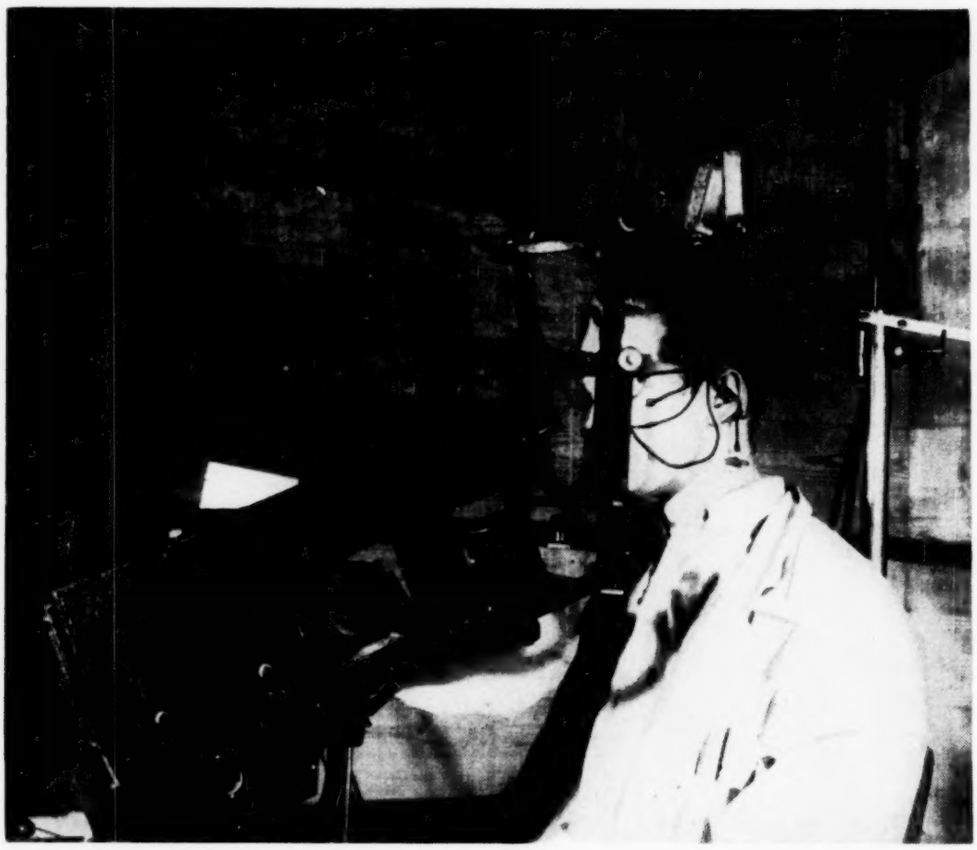


FIG. 3*B*. Side view showing subject in head holder ready for simultaneous electrical and photographic recording of eye-movements.

employed simultaneously because of the limitation of the number of amplifier channels and oscillographic units available to us.

The photographic records were made by employing a slightly modified commercial binocular eye-movement camera using film. This apparatus, the so-called Opthalm-O-Graph, had to be suitably shielded and electrically grounded before it could be used simultaneously with the electrical recording methods outlined above. Figure 3*A* shows a subject with the electrodes in place, and Fig. 3*B* shows the same subject with his head held for photographic eye movement recording and simultaneous electrical recording.

The voltage produced at any given experimental sitting was determined by reference to calibration records which were always made at the conclusion of each experiment. Measurement of both the oscillographic and the photographic records

was made on the enlargements projected onto a suitable screen. In both cases, a ratio of 1 to 10 was used. The oscillograms were recorded on opaque paper and were projected by the use of an ordinary reflecting projector so adjusted and focussed that the ratio mentioned above was maintained in all records. The film was similarly projected and measured by a modified form of microscopic slide projector.

As the result of several preliminary trials, it was decided to experiment with certain pairs of the four electrode placements in typical relationships. The first of these settings, here abbreviated as P_1, used as bipolar leads to Amplifier *A*, the left external and the right external electrodes. At the same time, the left superior and the left inferior electrodes were led to Amplifier *B*. The second placement, P_2, used the left external and left internal leads to Amplifier *A*, and the left superior and left inferior leads to Amplifier *B*. The third placement, P_3, used the left external and left internal to Amplifier *A*, and the right internal and right external to Amplifier *B*. The fourth placement, P_4, used the right superior and the right inferior to Amplifier *A*, and the right internal and right external to Amplifier *B*. These placements are shown diagrammatically in Fig. 4.

The movements of the eyes in reading were first studied with these four placements, but for a quantitative investigation, it was decided to use more standard conditions. For this purpose, a series of four cards was prepared on each of which four dots were arranged as shown in Fig. 5. The dots were separated respectively by 10 mm, 20 mm, 40 mm, and 60 mm. These stimulus cards were approximately 30 cm from the subject's eyes. The subject was instructed to fixate the mid-point between the dots and then, at a signal, to make ten horizontal excursions from one dot to the other on the same plane followed by a similar number of vertical excursions. These movements were timed by an electrical metronome beat.

Records, both directly photographic and electrical, were taken of eye-movements when observing all four cards, using each of the four placements noted above. Eight subjects

were used. There were thus available for correlation purposes 128 averages of film extent and of voltage for horizontal excursions, and 96 correlation averages for the vertical excursions (32 less since P_3 gave no consistent record of vertical

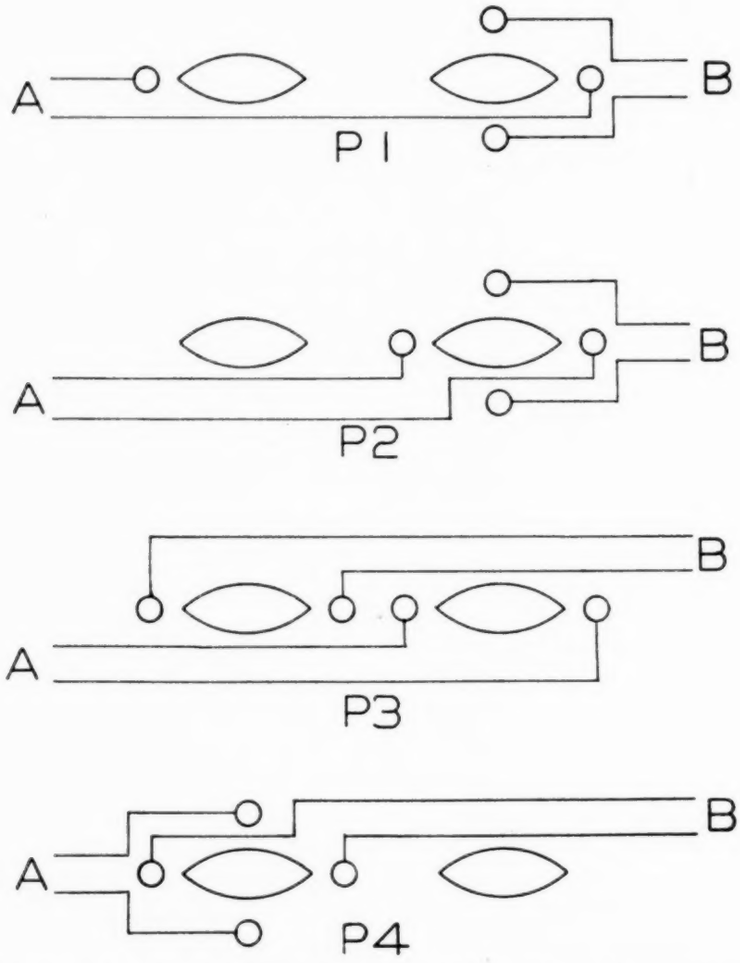


FIG. 4. Diagram of front view of placements used in this study. *A* and *B* indicate respectively the two amplifiers.

excursions due to the electrode placement). For each subject, there were 16 records (each of 10 movements) in the horizontal plane, 12 in the vertical, and 32 for each placement situation. Due to errors in recording, there were one or two records which could not be read clearly, but this fact did not materially affect the results and is taken care of statistically by the probable error of the correlations.

In each case, the average voltage was correlated with the average film extent of the eye or eyes involved in producing

the change in potential for that discrete situation. The photographic record was measurable only for the horizontal excursions of the eye; the statistical measures involving

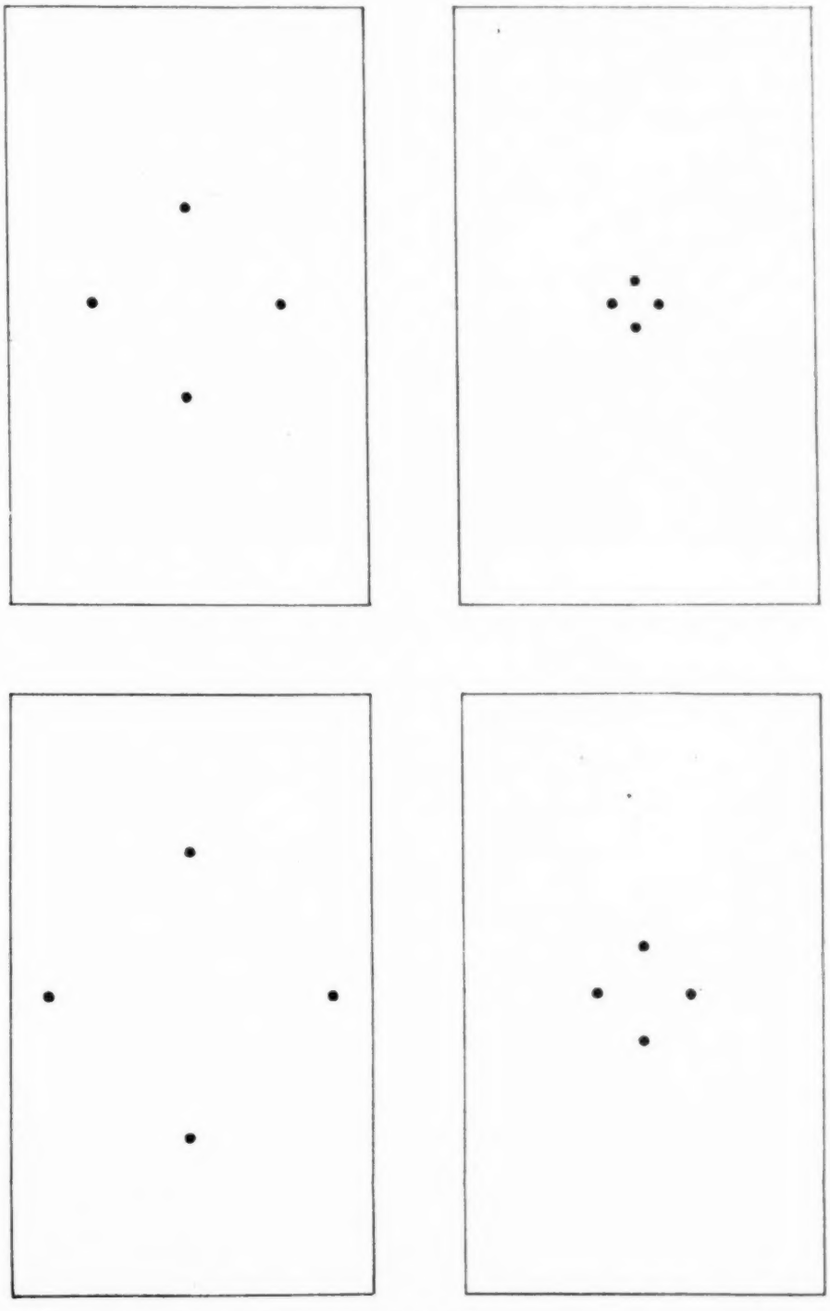


FIG. 5. Dot patterns used as guides for eye-movement excursions.

vertical excursions are not regarded as an integral part of this research. In comparing the correlations of film extent and voltage in the horizontal plane and those in the vertical

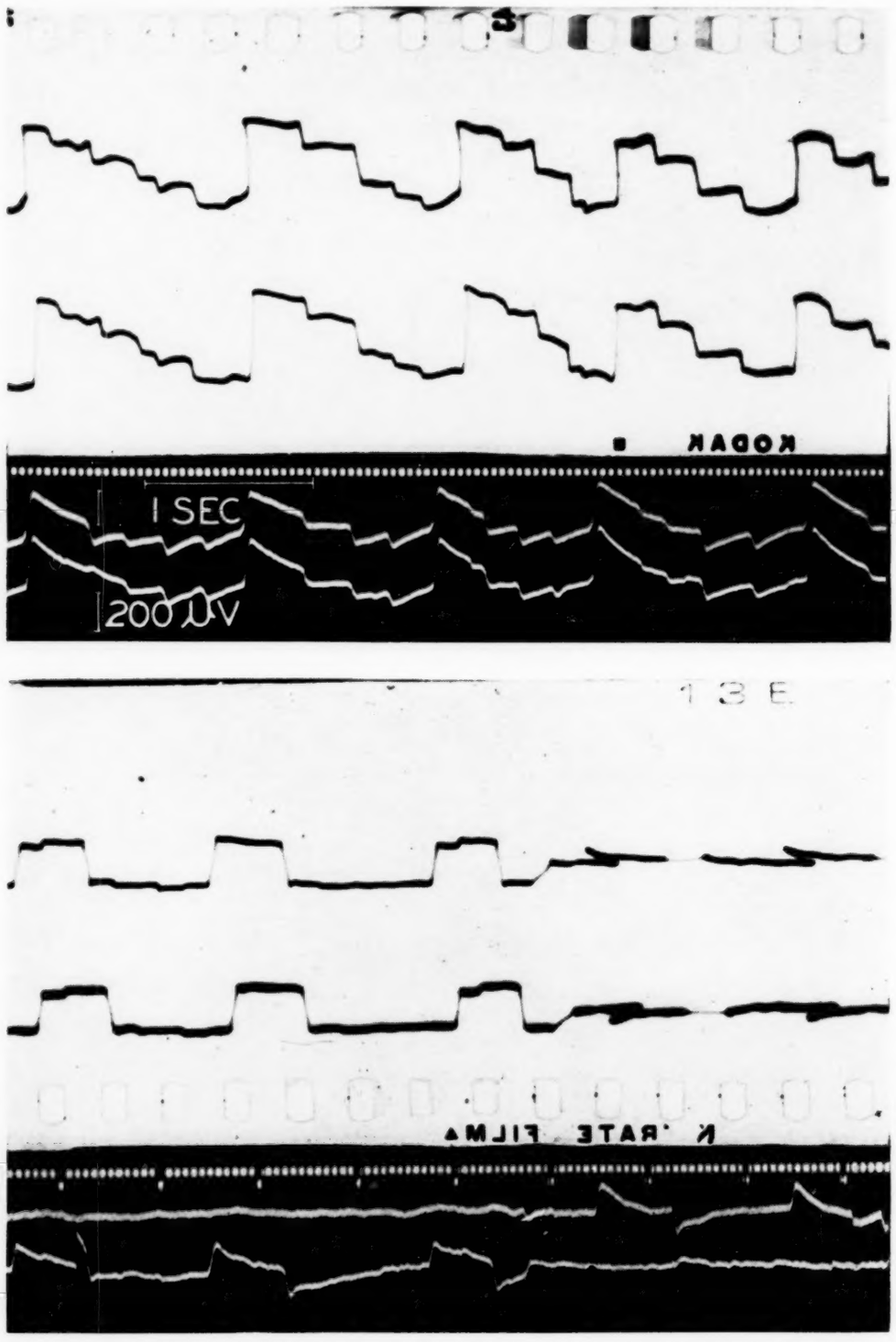


FIGURE 6*A* and 6*B* show samples of simultaneous electrical and photographic records. 6*A* shows a record of eye-movements when reading prose; 6*B* shows a record as made on the dot pattern. In this case, Placement P_2 was used. In all, five excursions are shown: the three at the left of this record were made of horizontal excursions, the two at the right of vertical excursions. This record graphically suggests some of the advantages and disadvantages of the two methods.

plane, it has been assumed that in this experimental situation, excursions in the vertical plane are comparable to those in the measurable horizontal plane. Averages of the individual measures in each situation were correlated rather than the original discrete simultaneous records, because in this way errors of measurement were reduced, at least from one point of view. Figure 6 shows samples of simultaneous records.

The correlations that have been computed from the data are included in Table 1. The Pearson *r* correlating the film

TABLE 1

CORRELATION TABLE

(Film Extent and Voltage)

Data Group	Horizontal	Vertical
Entire data	.77±.024	.64±.035
Subject I	.96±.014	.93±.027
II	.85±.052	.93±.027
III	.93±.024	.90±.039
IV	.94±.020	.94±.024
V	.94±.020	.91±.035
VI	.86±.045	.93±.028
VII	.94±.020	.97±.012
VIII	.93±.024	.89±.043
Placement 1	.85±.033	.86±.031
2	.83±.037	.81±.041
3	.76±.052	
4	.77±.050	.81±.041
	Card c	Card d
Time of fixation	.85±.044	.86±.047

extent and the voltage for all the data in the horizontal plane is .77, and for the vertical data, .64. Considering the data for each subject separately, the Spearman rank-difference correlations between the film extent and voltage in the horizontal plane range between .96 and .85, and for the vertical data, between .97 and .89. The Fisher *z* formula, which requires that the difference between the two correlations be at least twice the standard error of the difference to be significant, showed that the difference between the horizontal highest and lowest correlation value was 4.9 times the standard error of the difference, and for similar vertical correlations,

3.9 times, suggesting that there was some significant individual variation in the degree of film extent and voltage produced.

The third part of the correlation table presents the correlations for each placement. The Pearson r for P_1 is .85, for P_2, .83, for P_3, .76, and for P_4, .77 in the horizontal plane. The correlations for the vertical plane range between .86 and .81. The Fisher z formula for the horizontal highest and lowest correlation showed that the difference was only .12 times the standard error of the difference, 1.61 for the vertical, indicating that there was no significant difference among the placement situations.

From a perusal of the raw data, one is led to expect a rather high correlation value and not the computed .77 which

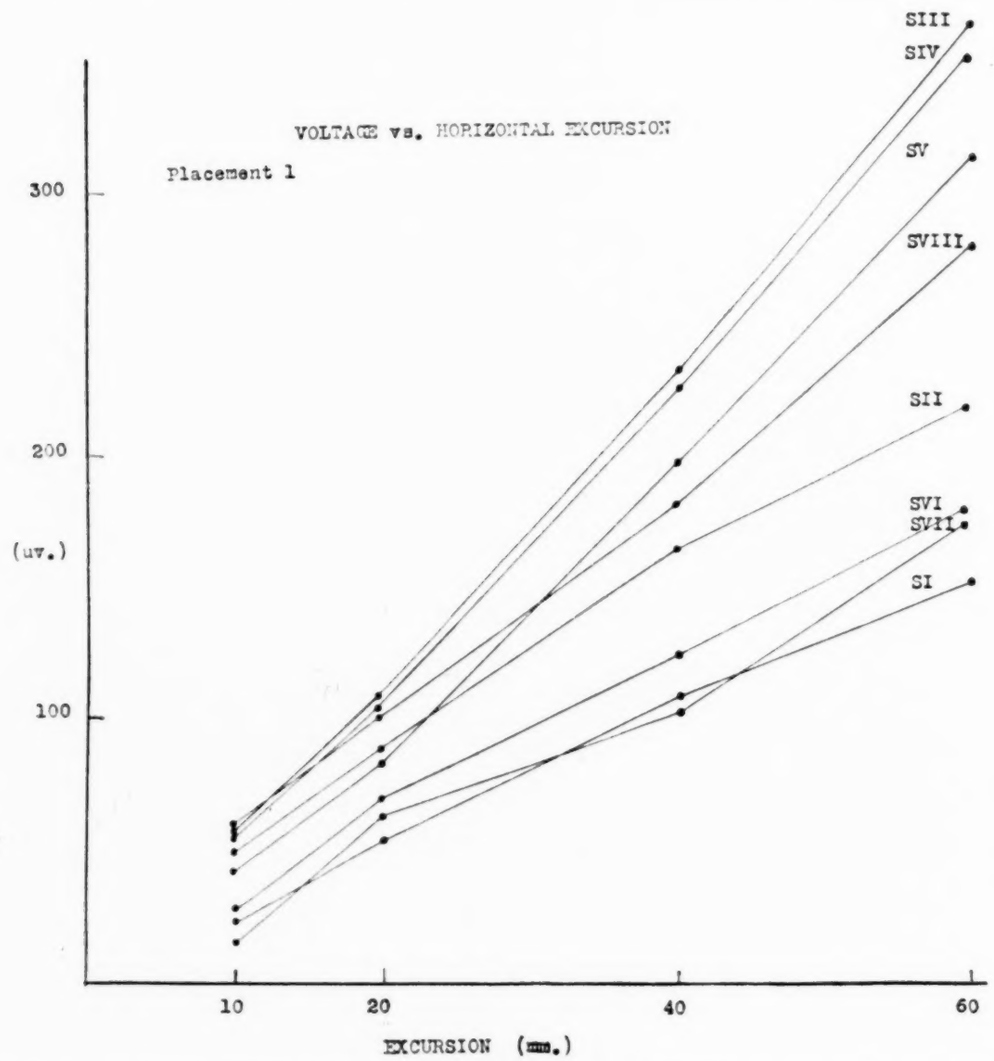


FIG. 7. Voltages versus horizontal excursion with Placement P_1 for eight subjects.

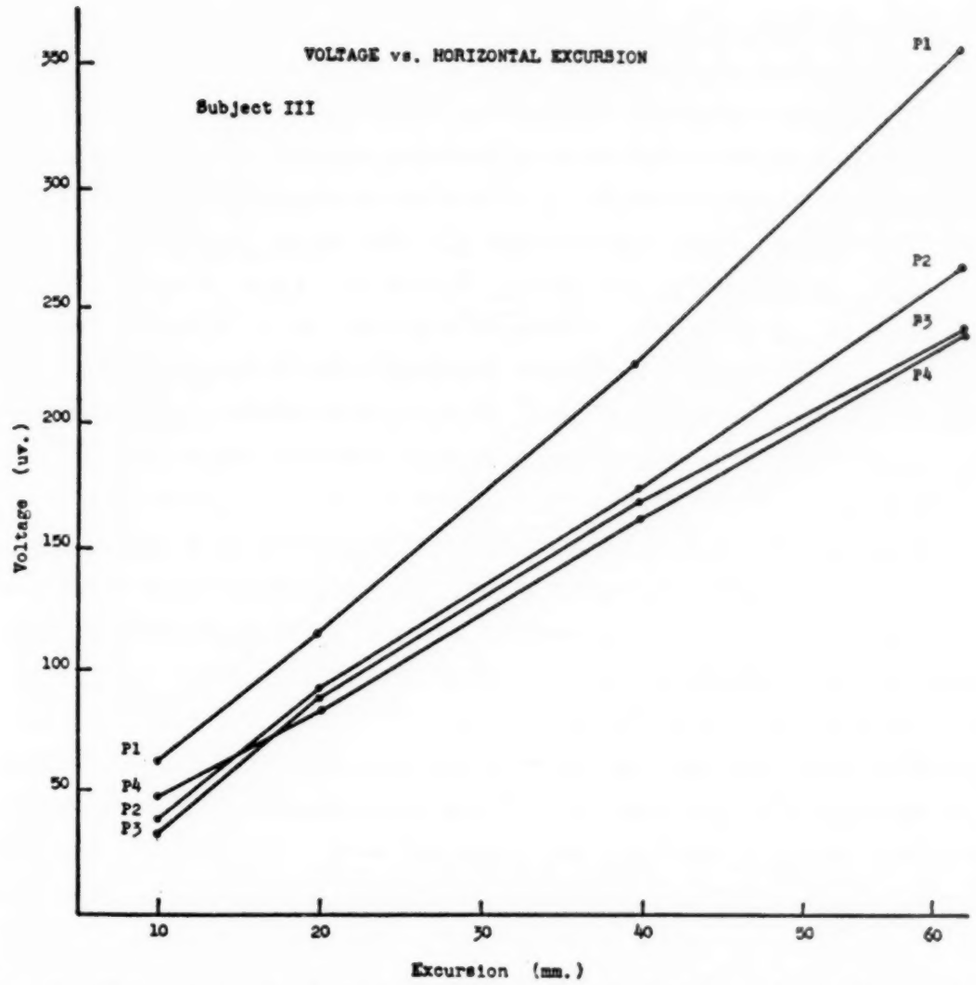


FIG. 8. Voltage versus horizontal excursion for a typical subject. Note Placement P_1 because both eyes are involved, showing consistently higher voltages.

thus requires some explanation. The requisite clue is in the findings of Fenn and Hursh (1) that the potential changes are, as a rule, consistent and peculiar to the particular subject, a finding which in other ways we have also confirmed in this experiment.

For each subject, the correlation has also been presented graphically, plotting in the first case voltage against film extent and in the second, voltage against excursion on the dot pattern card. The graphs tend to be straight line functions with the lines for Placements 2, 3, and 4 in a group. As would be expected, because both eyes are involved in P_1, there is a certain summation of voltages, and the records show a consistently higher voltage. Samples of our graphs are

shown as Figs. 7 and 8. All of these graphs indicate a good correlation of the voltage with the film extent or with the extent of the original excursion. In the study by Fenn and Hursh, it is reported that a calibration shows that the potential difference is proportional to the sine of the angle of deviation of the eyes. The excursions of the eyes involved in the present study were so small, however, that it proved not significant to plot the voltages secured as a function of the excursion in such a way as to indicate this curvilinearity. This formula of Fenn and Hursh should be remembered, however, when near-maximal excursions are recorded by this technique.

The results just given make us feel that it is possible to conclude that the changes in the corneo-retinal potential, as recorded by the oscillographic technique here described, are sufficiently constant and sufficiently correlated with the absolute degree of ocular excursion to constitute a reliable and satisfactory method of recording eye-movements in many psychological experiments. A few advantages of the electrical method may, therefore, be pointed out. It makes possible the study of the reflex adjustments and reactions of the eye in a totally dark room or in an experimental situation such as that required for the study of the autokinetic phenomenon in which a stimulus light of low intensity must be used. Movement of the eyes in emotional situations and in experiments whose procedure requires the subject to move his head or indeed his whole body may now be more normally and conveniently studied. This is possible because of the relative absence of restraint and interfering apparatus required by the electrical technique. It has, for example, suggested itself to the authors that the eye-movements of a motorist while driving in various traffic situations could be measured by this technique, although a number of special electrical details would have to be worked out before such registration would be possible. The electrical technique of eye-movement recording can also be used with young infants and with animals. One of the present writers has indeed participated in preliminary experiments using this method of recording the

eye-movements of young infants determined in a rotating drum such as to bring about optokinetic nystagmus. The conditions of this experiment suggest that the technique may be adapted so as to form an objective method of studying quantitatively the degree of 'night-blindness' resulting from Vitamin A deficiency even in newborn human infants.

Summary

This paper describes a quantitative comparison of the records of eye-movements made by the photographic corneal reflection technique and by a technique which makes possible the recording of changes in the corneo-retinal potential as determined by movements of the eyes in their orbits. The results show that for many purposes the electrical method is quantitatively reliable enough to be used in psychological research. Certain advantages of the electrical method, such as the fact that its use does not demand that the head be held absolutely rigid and that it can be used in complete darkness, may be pointed out.

(Manuscript received August 6, 1938)

References

1. Fenn, W. O., and Hursh, J. B., Movement of the eyes when the lids are closed, *Amer. J. Physiol.*, 1937, **118**, 1.
2. Jacobsen, E., Electrical measurements of neuromuscular states during mental activities. I. Imagination of movement involving skeletal muscles, *Amer. J. Physiol.*, 1930, **91**, 567.
3. ——, Electrical measurements of neuromuscular states during mental activities. III. Visual imagination and recollection, *Amer. J. Physiol.*, 1930, **95**, 694.
4. Meyers, I. L., Electronystagmography. A graphic study of the action currents in nystagmus, *Arch. Neur. & Psychiat.*, 1929, **21**, 901–918.
5. Mowrer, O. H., Ruch, T. C., and Miller, N. E., The corneo-retinal potential difference as a basis of the galvanometric method of recording eye-movements. *Amer. J. Physiol.*, 1936, **114**, 423–428.
6. Schott, E., Über die Registierung des Nystagmus und anderer Augenbewegungen vermittels des Saitengalvanometers, *Deutsch. Arch. f. klin. Med.*, 1922, **140**, 79–90.

AN ANALYSIS OF CONDITIONS INFLUENCING CONSONANCE DISCRIMINATION

BY EUGENE G. BUGG

Vanderbilt University

Since the days of Pythagoras thinkers have attempted to arrive at an existential definition of consonance which would meet with universal acceptance, but a survey of the theoretical and of the experimental studies dealing with consonance perception shows that this objective has not been realized. On the contrary, the reader is met with a baffling array of conflicting conceptions ranging from those which define consonance in purely cognitive terms (**4**) to those which, by identifying consonance with affective-tone actually deny its existence as a unique perceptual process (**2**, pp. 173–204). Undoubtedly this lack of agreement with respect to fundamental concepts is responsible for many of the contradictions obtaining among the various empirical studies of consonance. As a partial corrective for such over reliance upon definition arrived at largely by way of *a priori* speculation it is proposed that this concept be defined in terms of the concrete operations by means of which any set of so-called 'consonance judgments' is obtained.[1] In keeping with the notion that consonance 'means' the conditions under which 'such' perceptions occur the present study represents an attempt to gain further insight into the nature of 'this' phenomenon by analyzing the discriminations secured on paired-interval combinations under different sets of conditions.

Method of Procedure

In order to secure data for such analyses fifty paired-intervals were presented by means of the piano to eighty students in the introductory psychology course at Vander-

[1] The adoption of the operational point of view does not relieve us of the necessity of making definitive assumptions (and thus begging the question for the time being) at the outset of an empirical investigation. However, it does call for the re-evaluation and, if need be, the revision of such assumptions in the light of the data subsequently secured.

bilt University. Forty of the subjects were classed as 'untrained,' in that they had never received any musical instruction whatsoever. The remaining forty constituted the 'trained group,' each member having received at least three years of private musical instruction.

As indicated elsewhere (1, pp. 84–89), judgments of relative 'consonance' are most 'accurate' and consistent when the paired-interval combinations are so grouped that the subjects may apply a single appropriate criterion at a time. Accordingly, the fifty paired-intervals were divided into two series, which were presented separately. In the first series, consisting of the 29 combinations shown in Table 1, the subjects were instructed as follows:

TABLE 1

SHOWING PAIRS OF INTERVALS JUDGED ON THE BASIS OF RELATIVE *Smoothness*

1. Maj. 3rd–Maj. 7th	f′a′–b♭a′
2. Aug. 4th–Maj. 7th	a♭d′–a♭g′
3. Min. 7th–Maj. 2nd	a g′–a b
4. Maj. 3rd–Maj. 6th	f′a′–c′a′
5. Min. 7th–Maj. 7th	c′b′♭–c′b′
6. Min. 2nd-Maj. 2nd	f′♯g′–f′g′
7. Maj. 6th–Maj. 7th	a♭f′–a♭g′
8. Min. 2nd–Octave	a b♭–a a′
9. Min. 7th–Min. 2nd	c′b′♭–c′d′♭
10. Prf. 4th–Min. 2nd	g c′–b c′
11. Maj. 2nd–Min. 6th	g a–g e′♭
12. Maj. 7th–Min. 3rd	a g′♯–f′g′♯
13. Maj. 6th–Min. 7th	b g′♯–b a′
14. Prf. 4th–Maj. 3rd	c′f′–c′e′
15. Octave–Maj. 2nd	g g′–g a
16. Min. 2nd–Prf. 4th	b c′–g c′
17. Min. 2nd–Min. 7th	c′d′♭–c′b′♭
18. Maj. 7th–Maj. 6th	a♭g′–a♭f′
19. Maj. 2nd–Min. 2nd	f′g′–f′♯g′
20. Maj. 7th–Min. 7th	c′b′–c′b′♭
21. Maj. 6th–Maj. 3rd	c′a′–f′a′
22. Maj. 2nd–Min. 7th	a b–a g′
23. Maj. 7th–Aug. 4th	a♭g′–a♭d′
24. Maj. 7th–Maj. 3rd	b♭a′–f′a′
25. Maj. 2nd–Octave	g a–g g′
26. Maj. 3rd–Prf. 4th	c′e′–c′f′
27. Min. 7th–Maj. 6th	b a′–b g′♯
28. Min. 3rd–Maj. 7th	f′g′♯–a g′♯
29. Min. 6th–Maj. 2nd	g e′♭–g a

You will hear two tones (constituting an interval) sounded simultaneously, and then, after a brief period, a second pair. If the second pair is smoother than the first (*i.e.*, relatively free from beats and roughness), it is more consonant than the first, and you will record an *M* in the appropriate square on your record sheet. If the second pair is less smooth than the first, it is less consonant, and you will record an *L* in the proper square.

In the second series, which consisted of the 21 paired-intervals shown in Table 2, the judgments of the subjects were similarly recorded on the basis of relative *blending*, this criterion being defined as a tendency for two tones to agree or belong together. Before the presentation of these two sets of stimuli the meanings of the criteria were illustrated by means of certain pairs played on the piano. Also, the subjects were instructed to disregard the factor of agreeableness in making their comparisons.

TABLE 2

SHOWING PAIRS OF INTERVALS JUDGED ON THE BASIS OF RELATIVE *Blending*

1. Prf. 5th–Octave	e′♭ b′♭–b♭ b′♭
2. Min. 3rd–Min. 6th	g♯ b–g♯ e′
3. Dim. 5th–Min. 6th	d′a′♭–c′a′♭
4. Maj. 3rd–Min. 6th	g b–g e′♭
5. Min. 3rd–Maj. 2nd	a c′–b♭ c′
6. Dim. 5th–Maj. 3rd	e′b′♭–e′g′♯
7. Min. 7th–Prf. 4th	d′c″–d′g′
8. Min. 3rd–Dim. 5th	e′♭ g′♭–c′g′♭
9. Dim. 5th–Min. 6th	a e′♭–a f′
10. Min. 6th–Maj. 6th	d′b′♭–d′b′
11. Octave–Maj. 3rd	a a′–a c′♯
12. Maj. 2nd–Min. 3rd	b♭c′–a c′
13. Min. 6th–Maj. 3rd	g e′♭–g b
14. Min. 6th–Dim. 5th	c′a′♭–d′a′♭
15. Min. 6th–Min. 3rd	g′♯e′–g♯b
16. Octave–Prf. 5th	b♭ b′♭–e′♭ b′♭
17. Maj. 6th–Min. 6th	d′b′–d′b′♭
18. Min. 6th–Dim. 5th	a f′–a e′♭
19. Dim. 5th–Min. 3rd	c′g′♭–e′♭g′♭
20. Prf. 4th–Min. 7th	d′g′–d′c″
21. Maj. 3rd–Dim. 5th	e′g′♯–e′b′♯

After presenting the fifty paired-intervals under the above instructions the same combinations were given a second time as a 'preference series,' the subjects being instructed to use pleasantness and unpleasantness as the basis of comparison. Thus the subjects were to record the letter *P* if the second interval of a pair was more pleasing (*U*, if less pleasing) than the first. A week later the experiment was repeated, except that the preference series was presented first.

RESULTS

1. *General Comparisons of the Musically Trained and Untrained Subjects in Terms of 'Accuracy' and Consistency of Response*

In order to introduce a uniform basis for evaluating the subjects' responses to the paired-interval stimuli, both the consonance and the preference judgments were 'scored' in terms of degree of correspondence with Seashore's consonance

standards. It will be recalled that Seashore secured these standards by having a group of musical experts select what they regarded as the more consonant interval of each paired-interval combination in his so-called 'consonance test.' It is obvious that a psychometric 'test' of 'preference' is of questionable value, but it appeared that for the purpose of comparing the judgments of musically trained and untrained subjects with respect to gross total difference, the judgments might be 'scored' as 'correct' or 'incorrect' in terms of Seashore's norms. Thus to each subject was assigned two scores, one for the consonance series and one for the preference series. Average scores were computed for each of the two groups of subjects for the two types of discriminations called for.

TABLE 3

SHOWING THE MEANS, IN TERMS OF PERCENT CORRECT, THE STANDARD DEVIATIONS, AND THE RELIABILITY OF THE DIFFERENCES BETWEEN THE AVERAGES FOR 40 MUSICALLY TRAINED SUBJECTS, AND 40 UNTRAINED SUBJECTS, RESPECTIVELY

	Consonance			Preference		
	Mean	S.D.	Diff./Sigma Diff.	Mean	S.D.	Diff./Sigma Diff.
Trained subjects.....	80.77	4.98	6.82	76.27	6.70	2.48
Untrained subjects.....	71.90	6.58		71.20	11.06	

The data in Table 3 show that the musically trained group is 'superior' to the untrained group in judging relative consonance. The mean for the untrained group, in terms of percent correct, is 71.90, whereas that for the trained group is 80.77. This difference of 8.87 points has a 'critical ratio' (*i.e.*, Diff./Sigma Diff.) of 6.82. The trained subjects also scored higher when simply recording their preferences, the average score for this group being 76.27 as compared with 71.20 for the untrained subjects. The reliability index of this difference of 5.07 points, in terms of the above ratio, is 2.48. This superiority of the trained over the untrained subjects in judging relative consonance is shown in greater detail by means of Fig. 1. The fifty paired-interval combinations are represented on the X-axis, and the percentage of errors per

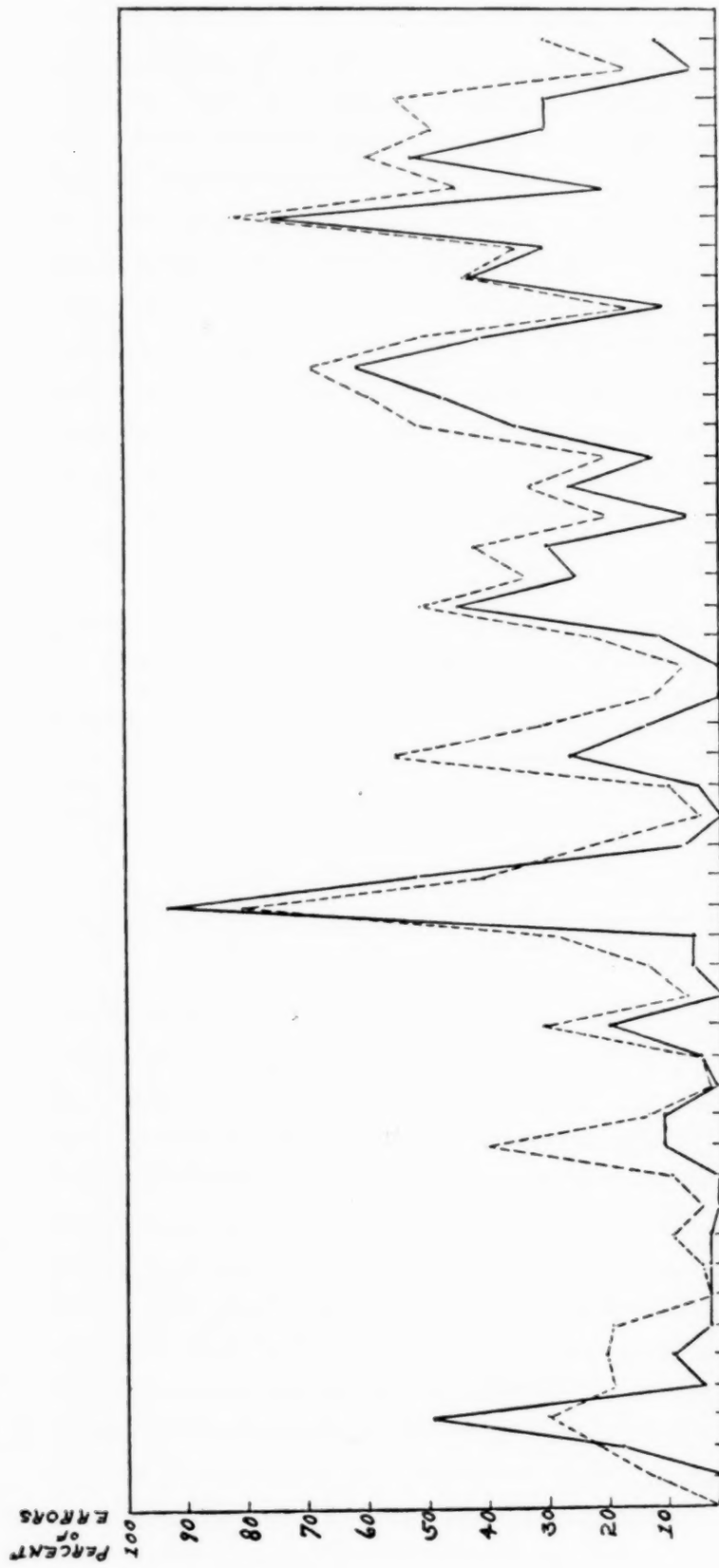


FIG. 1. Showing the error-percentages for the 40 musically trained subjects and the 40 untrained subjects on Seashore's fifty paired-interval combinations. The data for the trained subjects are represented by means of the solid line, those for the untrained subjects by the broken line.

combination on the Y-axis. The data for the trained subjects are represented by means of the solid line, those for the untrained subjects by the broken line. Figure 1 shows a rather general superiority on the part of the trained subjects, the error percentages for the latter being lower than those for the untrained on forty-four of the fifty paired-interval combinations.

In order to make further comparisons of the responses secured from our two groups of subjects the average number of judgment reversals made on the second presentation of each of the above series was computed.[2] By a judgment reversal is meant that the subject reverses his judgment on the second presentation of any given paired-interval combination with respect to interval preferred or as regards relative 'consonance.' It appears from Table 4 that the trained subjects were more

TABLE 4

SHOWING THE MEANS, IN TERMS OF JUDGMENT REVERSALS, THE STANDARD DEVIATIONS, AND THE RELIABILITY OF THE DIFFERENCES BETWEEN THE AVERAGES FOR 40 MUSICALLY TRAINED SUBJECTS, AND 40 UNTRAINED SUBJECTS, RESPECTIVELY

	Consonance			Preference		
	Mean	S.D.	Diff./Sigma Diff.	Mean	S.D.	Diff./Sigma Diff.
Trained subjects.....	9.27	3.23	6.40	9.47	3.91	2.60
Untrained subjects.....	14.75	4.34		12.00	4.71	

consistent than the untrained in their judgments of relative consonance. The average number of judgment reversals on the second presentation of the consonance series was 9.27 for the trained group, and 14.75 for the untrained. This difference of 5.48 points has a critical ratio of 6.40. The trained subjects were likewise more consistent than the untrained in recording their preferences, having an average of 9.47 judgment reversals as compared with 12 for the untrained subjects. The critical ratio of this difference is 2.60, which would be interpreted in conventional statistical terms as indicating that

[2] The problem of reliability indices of consonance judgments has been discussed at length in an earlier publication (1, pp. 58–59).

the chances are about 99 in 100 that this difference is a true difference.

In general, these comparisons show that our musically trained and untrained subjects constitute two 'statistically distinct' groups. This fact is of considerable importance for the following analyses which will undertake to show that consonance is not a simple unitary process but is rather a plurality of processes which tend to be influenced by several general factors including (1) affective-tone, (2) refinement of discriminations called for, (3) musical training, and (4) criteria employed. Furthermore, it will be pointed out that the factor termed 'affective-tone' is itself complexly conditioned, in some instances by circumstances which make for mutually opposing tendencies as regards interval preferences.

2. *Relative Influence of Affective-Tone upon the Discriminations of Musically Trained and Untrained Subjects*

As previously pointed out, the trained subjects show means of 80.77 and 76.27 on the consonance and the preference series, respectively. This difference of 4.5 points has a critical ratio of 3.36, thus indicating the existence of two fairly well-defined types of judgments on the part of some of the trained subjects. On the other hand, the average scores for the untrained subjects on the consonance series and the preference series are practically identical, being 71.90 and 71.20, respectively. As will be indicated presently in a more specific manner, the fact of the closer correspondence between the so-called 'consonance judgments' and the preference judgments in the case of the untrained subjects suggests that the latter were influenced to a greater degree by affective factors while attempting to discriminate relative consonance than were the trained subjects.

A comparison of the correspondence between the two types of judgments for the trained and the untrained subjects is shown in greater detail by means of Figs. 2 and 3. The fifty paired-interval combinations are represented in each figure on the X-axis and the percentage of errors per combination on the Y-axis. The data for the consonance judgments are repre-

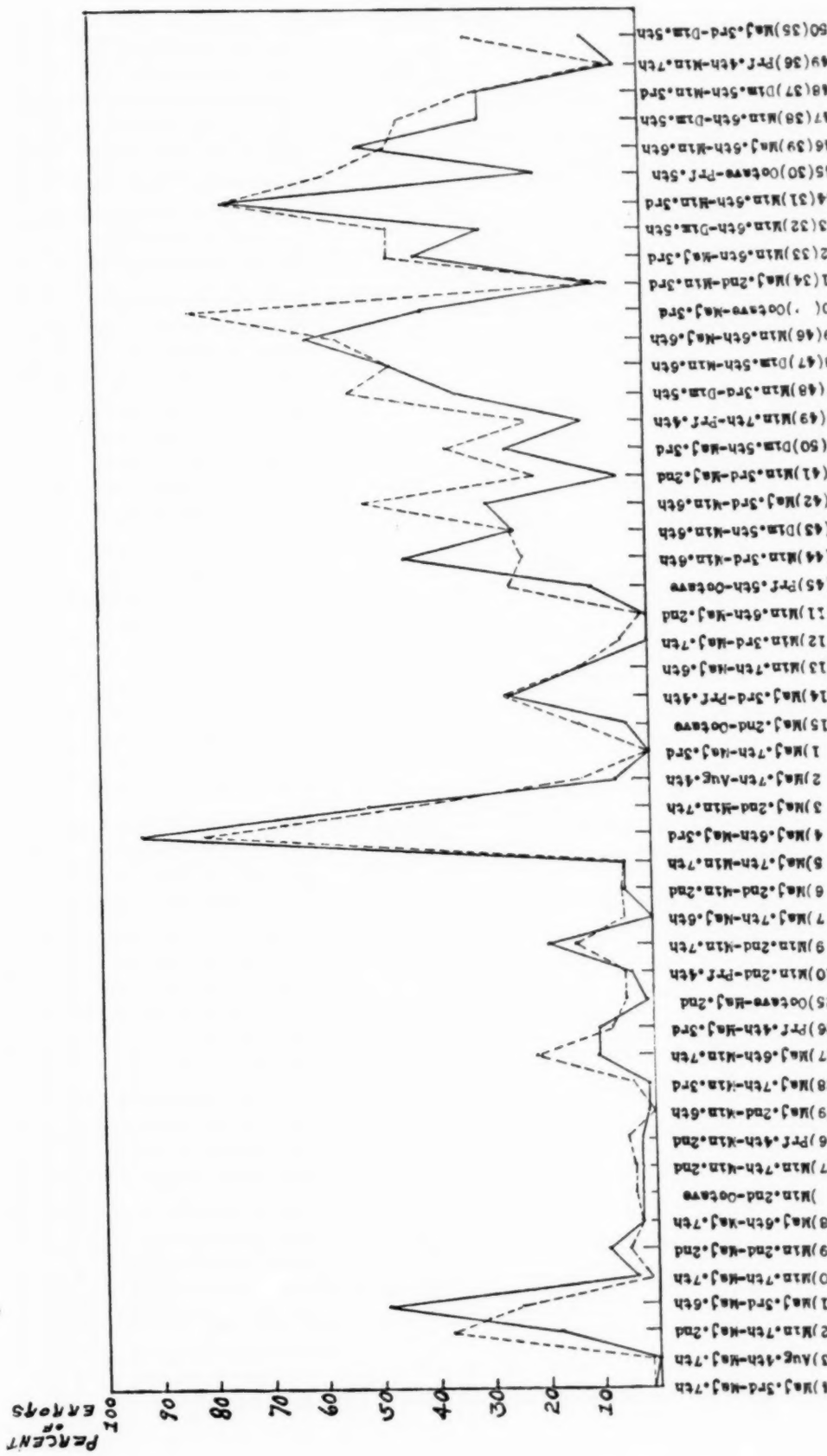


FIG. 2. Showing the correspondence between the 'consonance' judgments and the 'preference' judgments of the 40 musically trained subjects on Seashore's fifty paired-interval combinations. The data for the 'consonance' judgments are represented by means of the solid line, those for the 'preference' judgments by the broken line.

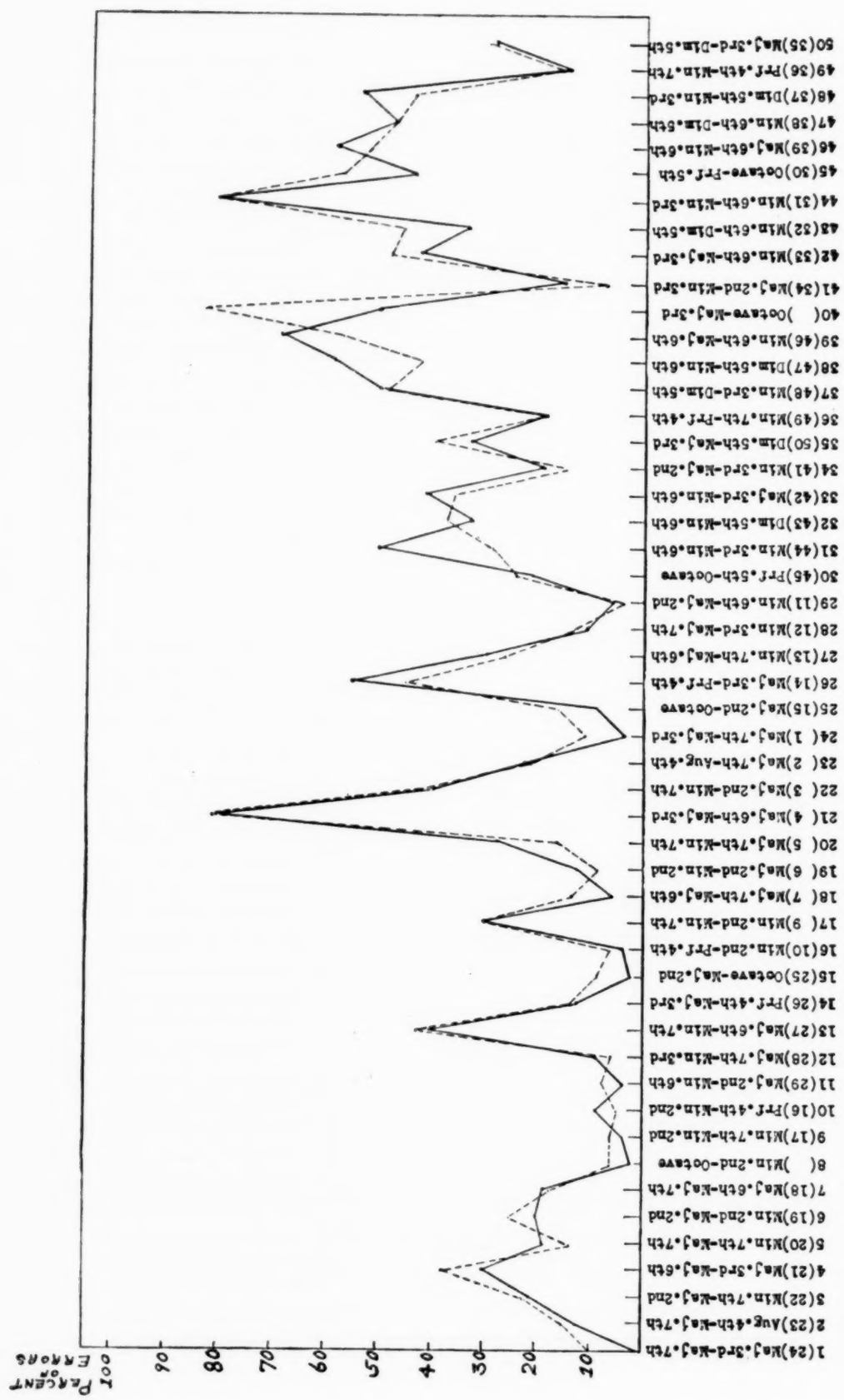


FIG. 3. Showing the correspondence between the 'consonance' judgments and the 'preference' judgments of the 40 untrained subjects on Seashore's fifty paired-interval combinations. The data for the 'consonance' judgments are represented by means of the solid line, those for the 'preference' judgments by the broken line.

sented by means of the solid lines, those for the preference judgments by the broken lines. The judgments secured for the trained subjects are shown in Fig. 2, those for the untrained in Fig. 3. For example, in judging combination 21 the untrained subjects had error percentages of 80 and 81.2 on the consonance series and on the preference series, respectively; whereas the corresponding percentages for the trained subjects were 92.5 and 81.0. Perhaps the most striking feature about Figs. 2 and 3 is the somewhat close correspondence between the *two types* of curves. In fact, in the cases of both the trained and the untrained subjects there is sufficient correspondence between the two curves to warrant the conclusion that in many instances the conditions determining the so-called consonance judgments were approximately the same as those determining the preference judgments. However, the two types of curves are more nearly identical in the case of the untrained subjects, thus suggesting that the latter were less successful than the trained subjects in disregarding the factor of affective-tone while attempting judgments in terms of relative *smoothness* and *blending*.

This conclusion is illustrated more specifically by the following analysis. Combination 4, which involves the Major Third–Major Sixth sequence, yields a difference of 23.7 points (in terms of percentage of errors) between the consonance and the preference judgments in the case of the trained subjects, as compared with a difference of only 7.5 units for the untrained subjects. Combinations 13 and 17 also show closer correspondence between the two types of curves for the untrained subjects. The results on combination 21 are strikingly similar to the above, both groups of subjects having an unusually high percentage of errors, the correspondence between the consonance judgments and the preference judgments being closer in the case of the untrained subjects. On the other hand, combinations 26 and 38 show closer correspondence for the two types of judgments in the case of the trained subjects. However, a point for point comparison of the two patterns would show, on the whole, a somewhat closer correspondence between the two types of curves for the un-

trained subjects. That such would be the case is shown by the fact that a correlation of .858±.028 exists between the percentages of error per combination on the consonance and the preference series for the trained subjects, whereas the corresponding coefficient for the untrained group is .918±.001. In view of the relative ease in discriminating between paired-intervals on the basis of pleasingness, it may be tentatively assumed that the closer correspondence between the two types of judgments [3] on the part of the untrained subjects indicates that the latter were influenced to a greater degree by affective factors in discriminating relative 'consonance' than were the trained subjects.

3. *Factors Determining the 'Affective-Tone' of Musical Intervals*

The foregoing discussion has shown that the so-called consonance judgments of both our trained and untrained subjects tended to be influenced by what has been collectively termed 'affective-tone.' However, by somewhat the same token that writers have been prone to regard consonance as a simple unitary affair so it has become customary to speak of affective-tone as though this term stood for a simply conditioned aspect of the tonal experience. It is the contention of the writer that an understanding of the perceptual responses of the subjects to certain paired-interval combinations involves the determination of the several ways in which affective-tone is itself conditioned, since the latter constitutes one of the factors regularly influencing so-called consonance judgments. The following analyses are concerned with two somewhat different 'types' of affective-tone both of which tend to influence judgments of relative consonance.

[3] The reader has doubtless observed that I hold the distinction between affective-tone and consonance to be a valid one. To identify the pleasing with the consonant would leave us with a new problem on our hands. A comparison of the 'consonance' with the 'preference' judgments on the Octave–Major Sixth combination shows that there is not a one-to-one correspondence between affective-tone and what has traditionally been termed consonance. Although the Major Sixth is regularly regarded as more pleasing than the Octave, the latter is usually judged to be the more consonant of the two. Now if consonance be defined as affective-tone, then another term must be found for the psychological experience which consists in recognizing that there is greater affinity between the component tones of the Octave than obtains in the case of the Major Sixth. *Introspectively, these experiences differ from each other and the issue is not clarified by the use of terms which fail to respect this difference.*

(*a*) *Order of Interval Presentation as a Determiner of Interval Preference*

As a means for indicating something of the complex manner in which affective-tone is frequently conditioned those paired-interval combinations in connection with which this factor seemed most prominent have been selected for study, the results being shown in Table 5. The values in this table represent the average percentages of error per combination for the trained and the untrained subjects on two presentations of the consonance and the preference series each. The results shown in Table 5 on combinations 3 and 22 indicate the

TABLE 5

SHOWING ERROR PERCENTAGES ON SELECTED PAIRS OF INTERVALS FOR 40 UNTRAINED AND 40 MUSICALLY TRAINED SUBJECTS

The italicized combination is considered by Seashore to be the more consonant.

Combination	Intervals	Trained Subjects		Untrained Subjects	
		Consonance	Preference	Consonance	Preference
3	*Min. 7th*–Maj. 2nd	17.5	37.5	21.2	22.5
22	Maj. 2nd–*Min. 7th*	51.2	45.0	40.0	41.2
4	Maj. 3rd–*Maj. 6th*	48.7	25.0	30.0	37.5
21	*Maj. 6th*–Maj. 3rd	92.5	81.0	80.0	81.2
9	*Min. 7th*–Min. 2nd	2.5	4.0	3.7	6.2
17	Min. 2nd–*Min. 7th*	19.0	14.0	30.0	30.0
14	Prf. 4th–*Maj. 3rd*	10.0	7.5	12.5	13.7
26	*Maj. 3rd*–Prf. 4th	25.0	26.0	55.0	45.0
30	Prf. 5th–*Octave*	10.0	25.0	21.2	23.7
45	*Octave*–Prf. 5th	20.0	57.5	43.7	57.5
31	Min. 3rd–*Min. 6th*	44.0	22.5	50.0	28.7
44	*Min. 6th*–Min. 3rd	75.0	76.0	81.2	81.2
35	Dim. 5th–*Maj. 3rd*	25.0	36.0	32.5	40.0
50	*Maj. 3rd*–Dim. 5th	10.0	31.0	28.7	30.0
39	Min. 6th–*Maj. 6th*	61.0	56.0	68.7	57.5
46	*Maj. 6th*–Min. 6th	51.0	46.0	58.7	52.5

influence which the order of presentation of intervals frequently exerts upon the judgments of subjects. When the Minor Seventh preceded the Major Second, the trained

subjects showed error percentages of 17.5 and 37.5 on the consonance series and the preference series, respectively. When the order of presentation of intervals was reversed, however, the corresponding percentages were 51.2 and 45. Likewise the untrained subjects showed a tendency to reverse their decisions upon a change in the order of interval presentation. In the case of combination 3, they had error percentages of 21.2 and 22.5 on the consonance series and the preference series, respectively. When the order of interval presentation was reversed in combination 22 the corresponding percentages for the untrained were 40 and 41.2. That the consonance judgments of both musically trained and untrained subjects tend to be conditioned by the sequence of intervals, by reason of the influence which this sequence has upon affective-tone, is suggested further by the results on pairs 30 and 45. The data on these combinations are typical in that they show a tendency for consonance judgments and preference judgments to vary in the same general direction upon reversal of the order of interval presentation. When the Fifth preceded the Octave (pair 30), the trained subjects had error percentages of 10 and 25 on the consonance series and the preference series, respectively. In other words, the Octave was regarded as the more pleasing in 75 percent of the cases and judged the more consonant in 90 percent of the cases. On the other hand, when the order of presentation was reversed the corresponding error percentages were 20 and 57.5. This means that the Octave was regarded as the more pleasing interval of the Octave–Fifth combination only 42.5 percent of the time, and, coincident with this loss in affective value, was judged the more consonant 80 percent of the time (as compared with 90 percent on the Fifth–Octave sequence). The reversal of consonance judgments incident to changes in the order of interval presentation was likewise pronounced in the case of the untrained subjects. When the Fifth preceded the Octave, the untrained subjects had an error percentage of 21.2, whereas when the order of presentation was reversed in pair 45 the number of errors more than doubled. Apparently, the probability of such intervals being judged 'consonant'

tends to vary directly with the frequency with which they are regarded as pleasing. It appears that when consonance judgment reversals incident to changes in the order of presentation of intervals are paralleled by similar shifts in affective value we have a measure of the influence of affective-tone upon so-called consonance discrimination, in so far as affective-tone is conditioned by the order of interval presentation.

Similar comparisons, involving the results on the entire fifty paired-interval combinations, show the above type of judgment reversal to be somewhat more pronounced for the untrained subjects. On the average, the order of presentation of intervals within a pair was found to make a difference of 10.35 points (in terms of percent of errors on the consonance series) in the case of the trained subjects as compared with 12.39 points for the untrained. The closer correspondence between the consonance and the preference judgments of the untrained, and the greater tendency of the latter to reverse their judgments upon reversal in the order of interval presentation indicate that untrained subjects are less successful in disregarding affective-tone, while discriminating relative consonance, than are the musically trained.

(*b*) '*Intrinsic Pleasingness*' *as a Determiner of Interval Preference*

As already indicated, the affective value of each interval is itself complexly conditioned, and it has sometimes happened that even the influence of the order of interval presentation upon consonance discrimination has escaped the attention of investigators by reason of their failure to take note of this complexity (**3**, pp. 49–81). This is especially true for the combinations involving the Major Third and the Perfect Fourth. The sequence of the Major Third followed by the Perfect Fourth constitutes a case of musical resolution, as does the Perfect Fourth followed by the Third. Hence, it has sometimes been held that if consonance discriminations are influenced by that form of musicality termed 'resolution,' the Third should be judged the more consonant interval for the Perfect Fourth–Major Third sequence, whereas the Fourth

should be judged the more consonant for the Major Third–Perfect Fourth sequence. That this conclusion over-simplifies the problem is seen from the following analysis. Table 5 shows that when the Perfect Fourth was followed by the Major Third (pair 14), the trained subjects had an error percentage of 10 for the consonance judgments. It is probable that two affective factors operated in favor of the 'correct' judgment in pair 14. In the first place, the Major Third is what might be termed the more 'intrinsically pleasing' of the two intervals. That is to say, if subjects are required to evaluate the various intervals of the diatonic scale in terms of *pleasingness*, the majority will rate the Third higher than the Fourth. Secondly, in passing from the Fourth to the Third a highly satisfactory resolution is effected. It seems likely that these conditions were partly responsible for the fact that the percentage of 'errors' on combination 14 was very low. When the order of presentation was reversed the error percentage increased to 25. Thus notwithstanding that the results on pair 26 are not in absolutely inverse ratio to those obtained on pair 14, the change in order of presentation of intervals had considerable bearing upon the discriminations, *i.e.*, several of the subjects reversed their judgments in pair 26. Whereas both affective factors operated in favor of the 'correct' judgment on pair 14, it seems likely that they made for mutually opposing tendencies when the order of presentation was reversed in pair 26. That is to say, in the instance of pair 26, the greater 'intrinsic pleasingness' of the Third doubtless tended to prejudice the subjects in favor of this interval, whereas the sequence of intervals tended to favor the Fourth. To maintain that if a subject judges the Third to be more consonant than the Fourth for both orders of presentation he is uninfluenced by affective-tone is to overlook the role which the factor termed 'intrinsic pleasingness' plays in the discriminations. Apparently, this factor more than offset the influence of resolution in the case of pair 26, and was doubtless partly responsible for the 'correct' judgment being given in 75 percent of the comparisons made by the musically trained subjects. The data for the untrained subjects on pairs 14 and

26 show tendencies similar to those just noted in connection with the musically trained.

4. *The Relation of the Consonance Judgments of Musically Trained and Untrained Subjects to:* (1) *the Criteria Employed and* (2) *the Refinement of the Discriminations Called for*

The complexity of factors influencing consonance discrimination is revealed further by a comparison of the results obtained under conditions calling for the use of the criterion *smoothness* with those secured when *blending* was employed. Figure 1 shows that, *on the whole*, the error percentages for both groups of subjects are higher on those combinations in connection with which *blending* was employed as the basis of judgment (combinations 30–50). This fact which is exhibited more concisely in Table 6 suggests that the discriminations of

TABLE 6

SHOWING AVERAGE ERROR PERCENTAGES FOR 20 MUSICALLY TRAINED AND 20 UNTRAINED SUBJECTS UNDER CONDITIONS CALLING FOR THE USE OF DIFFERENT CRITERIA

Criterion	Trained		Untrained	
	Mean	S.D.	Mean	S.D.
Smoothness	13.63	19.40	19.90	19.00
Blending	30.24	19.20	41.67	18.30

both the musically trained and untrained subjects tend to be conditioned by the criteria employed, the average error percentages being twice as high when *blending* was the criterion used.[4] Thus in terms of Seashore's norms, it appears that *blending* is the more difficult of the two criteria to apply, this

[4] Since the criteria *smoothness* and *blending* were not employed in judging both groups of combinations and since the differences referred to are not statistically reliable our data should be regarded as merely suggestive with respect to this conclusion. However, they are strikingly similar to results which the writer previously obtained by methods somewhat different from those employed in the present study (1, pp. 79–89). For example, it appears that the tones constituting the Major Third tend more nearly to 'blend' than do those composing the Major Sixth, whereas the latter interval is generally regarded as the 'smoother' of the two.

being especially true in the case of the untrained subjects. Although the musically trained are superior to the untrained in the use of the above criteria, Table 6 shows that their superiority is almost twice as pronounced on those combinations for which the criterion *blending* was employed. However, it should not be surprising that both groups of subjects showed relatively high error percentages on those combinations which were judged in terms of the criterion *blending*. In the first place, it seemed to the writer that the majority of those combinations which were judged in terms of relative *smoothness* (Table 1) are severally composed of paired-intervals which present striking dissimilarities" [5] whereas, with few exceptions, those combinations for which the criterion *blending* was employed (Table 2) approximate to each other rather closely and thus call for a highly refined type of discrimination. Secondly, other things being equal, *blending* is probably the more difficult criterion to apply. Not only is it difficult of explication, but when defined as a tendency for tones 'to agree or belong together' it seems to call for comparisons of a more explicit and complicated nature than are ordinarily involved in the use of *smoothness*. Under such conditions both musically trained and untrained subjects would find the criterion *blending* relatively difficult to employ (despite the fact of its appropriateness in any given case). Furthermore, evidence is available which would lead one to expect that untrained subjects would experience the greater 'difficulty' in employing any criterion demanding such explicit comparisons of musical concepts.[6]

[5] In terms of Seashore's norms (which in view of the writer's stand on operationalism are not to be regarded as absolutes), it might be said that the two intervals constituting any given combination belonging to this group tend to be quite unequal in so-called 'consonance value.'

[6] In a recent study (presented in a paper before the Southern Society for Philosophy and Psychology at Knoxville, Tennessee, April 15, 1938) the writer found that musically trained and untrained subjects exhibit striking differences as regards both musical preferences and the choice of the distinguishing criteria rhythm, harmony, and melody. However, the differences in favor of the musically trained are far more pronounced for the 'criterion judgments.' Presumably, the act of choosing distinguishing criteria involves a more explicit type of comparison than that which obtains in the case of udgments of preference.

Summary and Conclusions

1. The lack of agreement among psychologists with respect to the 'fundamental nature of consonance' suggests the adoption of an operational definition of this term. Such adoption would have a salutary effect upon studies dealing with this problem, since it would necessitate investigations having for their aim the correlation of sets of conditions with types of discriminations obtained.

2. Operationally, the fact that the criteria *blending* and *smoothness*, which occasionally give rise to conflicting judgments when applied to the same combinations, can be used as bases for distinguishing between paired-interval stimuli signifies the existence of more than a single type of 'consonance.'

3. The complex perceptual processes collectively termed 'consonance' are influenced by a plurality of conditions such as (1) musical training, (2) affective-tone, (3) criteria employed, and (4) refinement of the discriminations called for.

4. The affective-tone of each interval of any given paired-interval tends to be complexly conditioned. Affective-tone which is conditioned by the order of interval presentation should be distinguished from that which has been termed 'intrinsic pleasingness' (*supra*, p. 67f.). In some instances these affective factors favor the same interval, whereas in other instances they favor different intervals of a given paired-interval combination. This fact renders it difficult to analyze the several influences, of what has been collectively termed affective-tone, upon the so-called consonance judgments secured for certain combinations.

5. Musically trained subjects tend to be more 'accurate' and consistent than untrained subjects in discriminating relative consonance. This fact contradicts the more or less *a priori* contention which certain writers have made in support of a genetic theory of consonance, namely, that the more familiar one is with modern music (which abounds in discords) the more one tends to prefer the dissonances and hence the less able one is to discriminate relative consonance. It is extremely doubtful whether the fact of the increasing use made of discords in modern music lends support to a genetic

theory of consonance. It seems more likely that this freer use made of the so-called discords today is largely the result of a tendency towards greater realism in the treatment of an ever widening range of subjects.

(Manuscript received July 12, 1938)

References

1. Bugg, E. G., An experimental study of factors influencing consonance judgments, *Psychol. Monog.*, 1933, **45**, No. 201.
2. Guernsey, M., The rôle of consonance and dissonance in music, *Amer. J. Psychol.*, 1928, **40**, 173–204.
3. Larson, D. L., An experimental critique of the Seashore consonance test, *Psychol. Monog.*, 1928, **38**, No. 176, 49–81.
4. Leibniz, G. W., *Principes de la nature et de la grâce, Leibnitii epistolae ad diversos*, Leipsic: Breitkopf, pp. 240 (Epistel 154).

EXPERIMENTAL STUDIES OF THE JUDGMENTAL THEORY OF FEELING: III. THE ABSOLUTE SHIFT IN AFFECTIVE VALUE CONDITIONED BY LEARNED REACTIONS

BY HENRY N. PETERS

University of Missouri

Introduction

In the preceding accounts of 4 experiments it was demonstrated that a learning situation in which subjects are required to react positively to 5 Japanese words, by pronouncing, and negatively to another 5 Japanese words, by not pronouncing, results in an increase in the pleasantness of the former relative to the pleasantness of the latter.[1] This result is in harmony with the chief hypothesis of the Judgmental Theory that positive and negative reactions are the underlying determinants of pleasantness and unpleasantness. Since in these experiments the subjects ranked only the 5 positive and the 5 negative words, 10 words in all, the data tell only of the affective values of the 2 sets of words with respect to each other. There are at least 3 plausible interpretations of this inversion of the relative evaluations of the 2 sets besides the one favoring the judgmental hypothesis, namely, that the set reacted to positively increases and the set reacted to negatively decreases in affective value, each set changing irrespectively of the other. All 10 words might actually increase in affective value—such an expectation would follow from the hypothesis that sheer familiarity is a determinant of feeling tone; all 10 words might move down the scale of affection; or only one set of words might move, the other remaining

[1] Peters, H. N., Experimental studies of the judgmental theory of feeling: I. Learning of positive and negative reactions as a determinant of affective judgments, *J. Exper. Psychol.*, 1938, **23**, 1–25; II. Application of scaling to the measurement of relatively indifferent affective values, *J. Exper. Psychol.*, 1938, **23**, 258–269. This series is being assisted by a grant from the University Research Council, University of Missouri.

stationary. The experiment to be described herein was planned primarily for the purpose of determining the absolute shifts in affective value of the 2 sets of words brought about by the learning situation. The data of this experiment, along with those of the preceding experiments, will serve secondarily as a basis for comparison of the methods of single stimuli and rank order.

Experiment 5 differed from the preceding experiments in the method of obtaining the subjects' affective judgments and in the number of Japanese words evaluated before and after learning. The intermediate learning problem was the same as that of Experiments 3 and 4. A group of subjects labeled each of 49 words as either P or U, learned to pronounce 5 of them and not to pronounce another 5, then labeled each of the 49 words again as P or U. The significant variation in method here is the employment of 39 additional words among the stimuli to be judged at one time. The method of single stimuli was used because the methods of rank order and paired comparison would have been awkward with such a large number of items.

The percentage of P judgments received by any word shall be taken as an indicater of its absolute pleasantness. And accordingly any change in this percentage, from first to second judgment period, shall be taken to indicate a change in absolute pleasantness. The direction and extent of change in absolute pleasantness of the 2 sets of 5 words can be estimated by comparison of their respective changes in percentage of P judgments with the changes in percentage of P judgments for the additional (control) words.

It should be emphasized for the sake of clarity that the feature of this experimental setup that renders the judgments 'absolute' as opposed to the 'relative' judgments obtained in the preceding experiments is the increased number of words judged at one time and not the method of making the judgments, the method of single stimuli or the method of absolute judgments. When human judgments are made in absolute categories this form of statement does not make them any more absolute than avowedly relative judgments. This rela-

tivity of absolute judgments is clearly demonstrated in the realm of affective judgments by the balanced proportions of categorical judgments given to almost any randomly chosen set of stimuli,[2] and by the effect of contrast between stimuli upon such judgments.[3] The sense in which the term 'absolute' is used in this paper is the only one in which it is operationally definable, namely, as judgments relative to a specified set of other stimuli which are similarly judged at the same time and irrespective of another specified set. Thus, in so far as the 2 sets of 5 words are judged at the same time as 39 other words are judged, their respective judgments will be absolute with respect to each other. It should be remarked, however, that in so far as the 2 sets, the judgments of which are the primary concern, are judged simultaneously, the goal of absoluteness is fallen short of. The large number of additional words were employed with the view of establishing a fairly stable reference group, and thus minimizing this element of relativity.

Experiment 5

I. Procedure

A subject began the experiment by sorting 49 cards, each with a different Japanese word typed on it, into 2 small boxes. He was seated at a table with the boxes immediately in front of him, the boxes separated by a distance of about 6″. The one on the left had the word Unpleasant printed on it in large letters; the other bore the word Pleasant. The Japanese words included the 10 used in previous experiments, symbolized by the Roman numerals I–X, and 39 others taken from the same source.[4] The experimenter placed on the table the pack of cards and a sheet containing the following typed instructions.

Instructions for Sorting Pleasant and Unpleasant Words

Here is a pack of 49 cards each with a different Japanese word typed on it. It has been often remarked that a person's chief reactions to foreign words which are entirely strange to him are emotional—that is, reactions of liking or disliking. In this experiment we are interested in knowing your emotional reactions to these

[2] Beebe-Center, J. G., The law of affective equilibrium, *Amer. J. Psychol.*, 1929, **41**, 54–69. Cohen, N. E., The relativity of absolute judgments, *Amer. J. Psychol.*, 1937, **49**, 93–100.

[3] Bacon, M. M., Rood, E. A., and Washburn, M. F., A study of affective contrast, *Amer. J. Psychol.*, 1914, **25**, 290–293. Harris, A. J., An experiment on affective contrast, *Amer. J. Psychol.*, 1929, **41**, 617–624.

[4] Tsuru, S., and Fries, H. S., A problem im meaning, *J. Gen. Psychol.*, 1933, **8**, 281–284.

particular Japanese words. One of the quickest ways to get this information is for you to sort the cards into 2 boxes, placing in one box all the cards with words you seem to like, and placing in another box all those you seem to dislike.

Take each of the cards, beginning with the one on top of the pack, and look at the word typed on it. Continue to look at the word until you make up your mind as to whether you think it pleasant or unpleasant. If you think it pleasant, drop the card in the box marked PLEASANT. If you think it unpleasant, drop the card in the box marked UNPLEASANT. If after trying for some time you simply cannot decide whether a word is pleasant or unpleasant, then just guess—follow your 'hunch'—and drop the card in one box or the other. Do this with each card, taking the cards one at a time.

Please do not keep an account of how many cards you are putting in each box. Just disregard this. It does not make any difference how many cards you put in a box. The only thing that matters is whether a word strikes you as pleasant or unpleasant.

Please do this as quickly as you can. Do not waste too much time over any one word. Tell the experimenter when you are through sorting.

When the subject finished sorting the Japanese words he was conducted to a chair before the memory drum, and given the instruction sheet for learning. Ten Japanese words were typed on the drum and these appeared in 3 scrambled orders. The learning problem consisted in learning to pronounce 5 of the words whenever one of them appeared in the aperture and not to pronounce the other 5. The subject was unaware of how many of the words he was required to pronounce. The 5 positive words and the 5 negative words were the ones used similarly in Experiments 3 and 4. These sets of words will be symbolized respectively by the Roman numerals I–V and VI–X. The words I–V are the 5 which received the lowest mean rankings when all 10 words were ranked for the first time by a group of 121 subjects (Experiments 1 and 2). The subject was required to pronounce I–V. The criterion of learning was 5 perfect trials in succession. This procedure concerning the learning situation was the same as that of Experiments 3 and 4.

Immediately after the learning the subject proceeded to sort the 49 cards under the same conditions as before. Instead of giving him the sheet of instructions this time, the experimenter merely said, "Will you sort these again, placing the words that seem pleasant to you in this box, and those that seem unpleasant in this box?"

The minor details of this procedure were made as nearly as possible the same as those of Experiments 1–4. The pack of cards was carefully shuffled, 2 or 3 times in the presence of the subject, before each sorting. Sixty subjects, 48 men and 12 women, were used in the experiment. All were naïve subjects.

II. Results

The mean numbers of trials and errors required by these 60 subjects to complete the learning problem, to the criterion, were only slightly greater than those for the subjects of Experiments 3 and 4. These means and their sigmas are, for trials and errors, 13.02 ± 0.94 and 33.08 ± 2.51. The original judgmental data of Experiment 5 consisted of the recordings for each subject of a P or a U for each of the 49 Japanese words,

both before and after learning. The number of words judged pleasant per subject (and, of course, the number judged unpleasant) was fairly uniform on both occasions. The mean, with its sigma, of the number of P judgments per subject is 26.72 ± 0.47 before learning; and 25.18 ± 0.83 after learning. Thus the percentage was close to 50 on both occasions.

The percentage of P judgments received by each of the 49 words before and after learning are presented in Table I. In the first and fourth columns appear the symbols of the words arranged in order of increasing percentage before learning. The 10 words used in the learning problem are symbolized by Roman numerals. In the second and fifth columns are the percentages obtained on the first sorting; in the third and sixth columns, the percentages on the second sorting. Figure 1 presents these data in graphic form. Along the base line the stimuli are arranged in their rank order before learning; the percentages of P judgments are shown on the ordinates. The solid line connects the percentages of P judgments for the successive stimuli before learning; the broken line connects the percentages for the same stimuli after learning. The change in percentage of P judgments, from before to after learning, for each stimulus word is indicated by the disparity between the 2 lines at the corresponding ordinate.

The striking feature of the results presented in Table I and in Fig. 1 is the relatively great change in the percentage of P judgments for each of the words I–V. The differences in percentage of P judgments, second minus the first, for these words are, +31.7, +28.4, +30.0, +25.0, +35.0. Only 8 of the other 44 words increased in affective value after learning, and the percentage increase for the one of these changing the most, word 6, is only +11.7, which is less then ½ the size of the smallest of the 5 changes listed above for I–V. It is therefore obvious that the positive reactions attached to these words during learning operated to increase their absolute pleasantness.

The effect of the learning situation on the 5 negative words, VI–X, is not so obvious. While all 5 decreased in percentage of P judgments, so also did 29 of the 39 words which were not

TABLE I

PERCENTAGE OF P JUDGMENTS GIVEN EACH WORD ON THE FIRST AND SECOND SORTINGS OF EXPERIMENT 5

Words	First Sorting	Second Sorting	Words	First Sorting	Second Sorting
1	23.3	20.0	VII	53.3	35.0
2	30.0	21.7	22	53.3	40.0
3	30.0	20.0	23	55.0	41.7
4	30.0	28.3	V	56.7	91.7
5	31.7	21.7	IV	56.7	81.7
6	33.3	45.0	24	60.0	63.3
7	35.0	30.0	VI	60.0	51.7
8	35.0	40.0	25	61.7	53.3
9	35.0	40.0	26	63.3	48.3
10	36.7	41.7	IX	70.0	48.3
11	38.3	41.7	27	70.0	61.7
I	38.3	70.0	28	70.0	68.3
12	40.0	31.7	29	70.0	68.3
13	41.7	33.3	30	71.7	58.3
II	43.3	71.7	31	71.7	55.0
III	43.3	73.3	32	73.3	68.3
14	45.0	36.7	33	76.7	68.3
15	45.0	45.0	34	76.7	50.0
16	46.7	43.3	35	76.7	58.3
17	46.7	46.7	36	76.7	66.7
VIII	50.0	30.0	X	78.3	61.7
18	51.7	58.3	37	81.7	75.0
19	51.7	43.3	38	85.0	78.3
20	51.7	40.0	39	96.7	91.7
21	53.3	60.0			

used in the learning situation. The words VI–X changed in percentage of P judgments the following amounts, −8.3, −18.3, −20.0, −21.7, −16.6. The mean change in percentage for the 39 extra words was -5.6 ± 1.2. The largest decrease in percentage obtained for any word, −26.7, was for one of these 39 words, word 34. Yet a superficial examination of the changes in percentage of P judgments for these 2 sets of words, VI–X and 1–39, enhances the belief that the negative reactions of the learning situation slightly reduced the pleasantness of VI–X. Each of the 5 minus changes in percentage for words VI–X is larger than both the mean and median changes for words 1–39; when all 44 words are considered as one distribution, 4 of the 5 words VI–X are found in the fourth quartile; and of the words 1–39 only 3 attain a percentage loss of −16.6 or greater, while 4 of the words VI–X suffered such a loss. Before submitting this comparison of

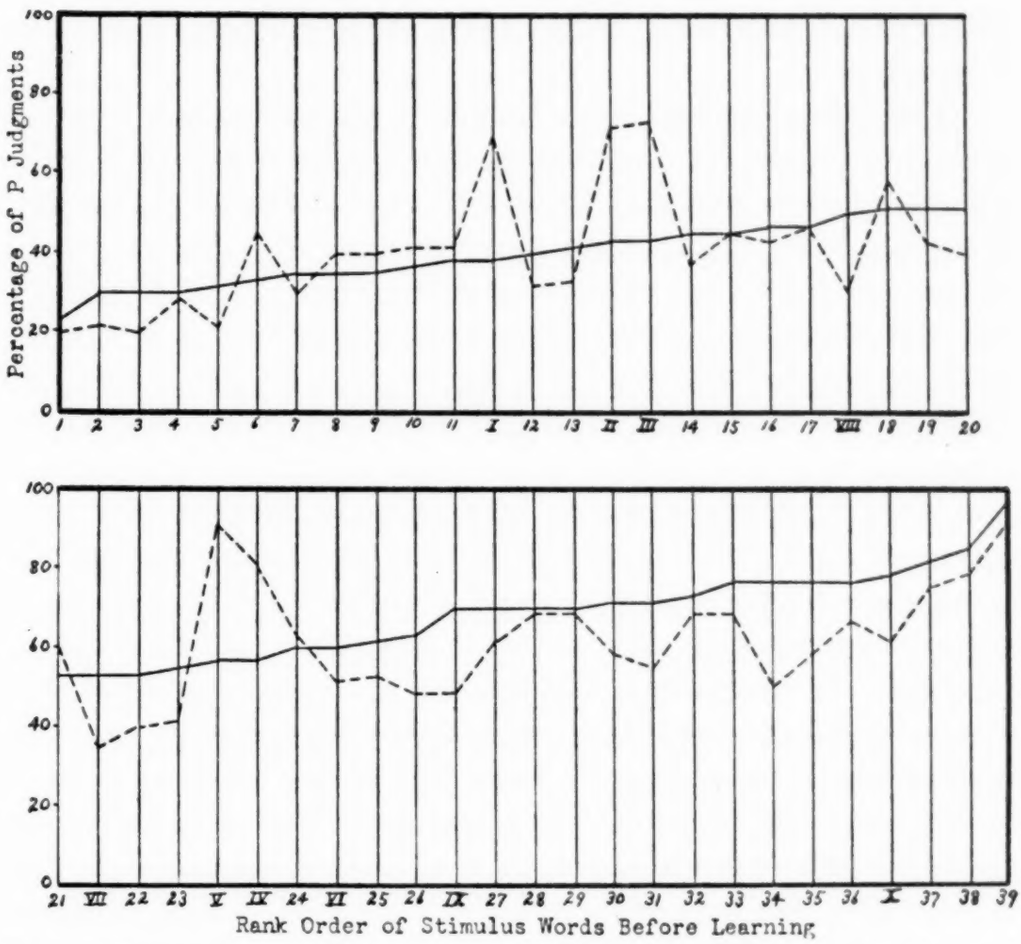


FIG. 1. The percentage of P judgments received by each word before learning (———) and after learning (— — —).

1–39 and VI–X to rigorous statistical test, however, the operation of 2 extraneous [5] influences on the changes in percentage of P's should be considered, especially since one of them vitally concerns this comparison.

The fairly uniform decrease in percentage of P judgments for all words but I–V, which is apparent from Fig. 1, is undoubtedly a contrast effect. The great increase in the number of P's for 5 words, which threatened to upset the 'equilibrium' of the 2 categories, was counterbalanced by a random distribution of U's to the remaining 44 words. There is no apparent reason why this contrast effect during the second sorting should not have operated equally on words 1–39 and on VI–X. Hence, for the present purpose of determining whether or not VI–X shall be considered as belonging to a

[5] These 2 influences are extraneous to the particular problem of the present study.

different distribution from 1–39, this influence may be ignored.

The other extraneous influence is one of chance. Words receiving on the first sorting less than 50 percent of P judgments are more likely as a result of chance factors to undergo a change toward increased percentage of P judgments on a second sorting than are words receiving more than 50 percent P judgments; and, conversely, words receiving at first more than 50 percent P's are more likely to decrease in this percentage on a second sorting. Evidence that this factor operated to produce the changes observed in 1–39 lies in the fact that 5 of the 8 words increasing in percentage of P's received on the first sorting less than 50 percent P's and the remaining 3 received little more than 50 percent. None of the words 1–39 receiving over 60 percent P's on the first sorting increased in percentage after learning. Since none of the words VI–X received less than 50 percent P's on the first sorting and 17 of the words 1–39 did receive less, this chance factor is not equalized for the 2 sets and thus a comparison of them directly cannot serve as the basis for estimating the influence of the learning situation on VI–X. This obstacle was overcome in the following manner.

For each of the words VI–X a single measure of percentage change in P judgments was extracted from 1–39, this measure representing the change for a word which received on the first sorting a corresponding percentage of P judgments. Thus if one of the words 1–39 received an original percentage the same as the test word, its percentage of change was taken; if more than one of the 39 control words received the same original percentage, the mean was taken; if no control word received the same original percentage, the mean of the changes in percentage for the words receiving the next highest and next lowest original percentages was taken, or, in case more than one word received either or both of the adjacent original percentages, the means were first determined for the 2 adjacent percentages separately and then the 2 means were averaged. Inspection of the second and fifth columns of Table I, in particular the words 1–39 adjoining the words

VI–X, will reveal that all of the above methods of extracting a corresponding percentage of change were necessitated. This procedure yielded a test and a control series of 5 measurements each, the 2 series differing only with respect to the learning situation. Fisher's *t*-test was employed in estimating the significance of the difference between the 2 series.[6] The mean difference between the 2 series, test minus control, is −13.3 percent. When the 2 series are treated as separate, unpaired series, $t = 4.054$ which, with $n = 8$, lies beyond the limits of the table of *t*, signifying a P of less than .01. When the 2 series are treated as a series of related pairs and the differences between pairs of measurements taken, $t = 5.870$ which, with $n = 4$, also lies beyond the limits of the table of *t*. Thus the difference between the 2 series could have occurred by chance with a probability of less than 1 out of 100, and may be considered very significant.

In the same manner the percentages of change in P judgments for the words I–V were compared with 5 control percentages. The mean difference between the 2 series is +33.9. When they are treated as 2 separate series, $t = 13.673$; and when treated as a series of corresponding pairs, $t = 15.949$. Both of these *t*'s, for the corresponding *n*'s, lie far beyond the limits of the table.

It may be confidently concluded from the data of Experiment 5 that the effect of learning positive reactions to the Japanese words is to increase their absolute affective value and that the effect of learning negative reactions is to decrease absolute affective value. It may be concluded further that the effect of positive reactions, in the direction of raising, is stronger than the effect of negative reactions, in the direction of lowering affective value. The inextricable admixture of contrast and chance influences to the changes in percentages of P judgments precludes any more definite estimate of the relative strengths of the 2 effects, although these relative strengths probably approach a ratio of 2 : 1. A condition in which a comparable group of subjects sorted the 49 words,

[6] Fisher, R. A., *Statistical Methods for Research Workers*, 6th ed., Edinburgh, Oliver and Boyd, 1936, esp. p. 133.

rested for half an hour, and sorted a second time would make such a disentanglement of influences possible.

Comparison of the Methods of Single Stimuli and Order of Merit

Table II presents the pooled results obtained with the words I–X in Experiment 5 and in Experiments 1–4. In

TABLE II

Percentages of P Judgments Received by the Words I–X in Experiment 5 and the Mean Rank Orders of the Same Words in Experiments 1 and 2 and in Experiments 3 and 4

Words	Percentage of P Judgments		Mean Rank Orders	
	First Sorting	Second Sorting	Experiments 1 and 2, R_1	Experiments 3 and 4
I	38.3 (1)	70.0 (6)	3.59	4.83 (4)
II	43.3 (2.5)	71.7 (7)	3.70	5.84 (6)
III	43.3 (2.5)	73.3 (8)	4.82	6.19 (8)
IV	56.7 (6.5)	81.7 (9)	5.31	6.15 (7)
V	56.7 (6.5)	91.7 (10)	5.54	6.81 (10)
VI	60.0 (8)	51.7 (4)	5.55	4.76 (3)
VII	53.3 (5)	35.0 (2)	5.87	4.22 (1)
VIII	50.0 (4)	30.0 (1)	5.97	4.60 (2)
IX	70.0 (9)	48.3 (3)	6.69	5.21 (5)
X	78.3 (10)	61.7 (5)	7.97	6.40 (9)

Experiments 1–4 the order of merit method was used; the subjects ranked the 10 words twice in Experiments 1 and 2, in Experiments 3 and 4 the subjects ranked the words only after learning. The first column of the table contains the symbols for the words; the arrangement of the words is in order of increasing mean rank orders in the composite first rankings of Experiments 1 and 2, which are presented in the fourth column. The second and third columns present the percentages of P judgments received by the 10 words before and after learning in Experiment 5. The fifth column shows the mean rank orders obtained from a pooling of the rankings after learning in Experiments 3 and 4. The numbers in parentheses indicate the rank orders of the means or percentages. These are omitted for Experiments 1 and 2, because the means of this column are listed in rank order. Thus the first 2 columns

of figures show the relative rankings before and after learning by the method of single stimuli; the last 2 columns show the relative rankings before and after by the method of rank order. In both cases increasing size of the figure indicates increasing affective value.

The rank order of the 10 words obtained in the first sorting of Experiment 5 and in the first ranking of Experiments 1 and 2 are closely similar. The lowest 3 and the highest 2 words are the same by both methods. The percentage of P judgments have been plotted against the mean rank orders, and the plot found to be obviously linear. Rank order correlation between the figures of the 2 columns yields a rho of .80. The agreement between the 2 methods is about the same as the agreement found between the mean rankings of Experiment 1 and Experiment 2, a rho of .81 being found between the latter. The second sorting of the 10 words in Experiment 5 shows a similar degree of closeness to the mean rank orders of Experiments 3 and 4. The plot of these 2 was found to be linear; and rank order correlation yields a rho of .81. A rho of .79 was found between the mean rank orders of Experiment 3 and those of Experiment 4. The agreement between the method of single stimuli and the order of merit method on the relative affective values of the words before and after learning is certainly as close as could be expected. Both methods reveal the tendency toward inversion of the relative positions of the positive and negative words. And by both methods the 5 members of each set of words, positive and negative, maintain after learning approximately the same standing relative to each other that they held prior to learning.

There are 2 differences in the shifts in affective value indicated by the 2 methods which imply a greater sensitiveness of the method of single stimuli to the influence of the learning situation. With the method of single stimuli the inversion of the 2 sets of words, from first to second judgment period, is more complete than with the order of merit method. Whereas in terms of percentage of P judgments the 5 positive words, I–V, occupy the 5 highest ranks after learning, in terms of mean rank order only 4 of the positive words are in the highest

5 ranks, word X taking rank 9 and word I taking rank 4. In the second place the 2 methods differ in that they show opposite effects of the learning situation on the range of affectivity covered by the 10 words. With the method of single stimuli, the range increases after learning; with the method of rank order, the range narrows. In terms of percentage of P judgments the range increases from 40.0 to 61.7. The range in mean rank orders of 4.38 obtained in Experiments 1 and 2 reduces to a range of 2.59 in Experiments 3 and 4.

It is especially remarkable that this greater sensitivity to the effect of the learning situation shown by the method of single stimuli in Experiment 5 as compared to the order of merit method in Experiments 1–4 occurs in spite of a factor present in the former, and absent in the latter, which has been found to act against the appearance of the influence of the learning situation as measured by the method of rank order. In Experiment 5 the same group of subjects sorted before and after learning, whereas the 2 rank order results, those of Experiments 1 and 2 and those of Experiments 3 and 4, were obtained from different groups of subjects. In Experiment 1 it was found that when the same group of subjects judged by the order of merit method before as well as after learning, the effect of the learning situation failed to appear in the mean rank orders of the whole group. Thus not only is the method of single stimuli to be recommended for its greater responsiveness but also because it makes possible the use of the same group of subjects for judging before and after a conditioning situation, which is an advantage that weighs heavily in terms of economy of the experimenter's effort.

This greater responsiveness of the method of single stimuli has already been reported by Conklin and Sutherland.[7] These writers ascribe this quality to the immediacy of the type of judgment required by this method as opposed to the analytical attitude accompanying the rank order judgments. In the present study it is probable that this increased responsiveness, to an influence in opposition to the original affective values, is at least in part due to the additional

[7] Conklin, E. S., and Sutherland, J. W., A comparison of the scale of values method with the order-of-merit method, *J. Exper. Psychol.*, 1923, 6, 44–57.

number of words judged with the method of single stimuli which should weaken the subject's memory of the previous judgment of any one of the 10 words used in learning.

Conclusions

The following conclusions have been reached in the present study:

(1) A learning situation in which positive reactions are connected to some words and negative reactions to others results in an increase in the absolute affective values of the former and a decrease in the absolute affective values of the latter.

(2) The effect of positive reactions in one direction is stronger than the opposing effect of negative reactions.

(3) Results obtained by the method of single stimuli, allowing 2 categories of judgment, duplicate those previously obtained by the method of rank order.

(4) Of the 2 methods, the method of single stimuli is more sensitive to the effects of the learning situation.

(Manuscript received July 26, 1938)

THE RELATIONSHIP BETWEEN SPEED AND EFFICIENCY OF LEARNING ON THE CONSTANT SPEED FINGER MAZE

BY WINFORD L. SHARP

College of Wooster

This paper has two purposes: first, to describe a modified type of finger maze, which we believe to have certain marked advantages for experiments with human subjects; second, to present the results of an investigation concerning the relationship between speed and efficiency in maze learning.

One basic limitation of the maze as a device for learning investigations is the uncontrolled factor of the speed at which the subject progresses in any given trial. As one watches subjects at work in a maze he is impressed by the following facts: (1) the speed of any given subject varies widely from trial to trial, decreasing, though not consistently, as the learning advances; (2) the speed of one subject as compared with that of another may vary greatly. Speed has commonly been used as a criterion of learning, but never apart from errors and sometimes the two criteria have not agreed. It was to overcome such difficulties that the maze herein described was devised.

Apparatus and Method

This maze is essentially a finger maze constructed after the following manner. A strip of heavy-gauge galvanized iron, 9½ inches wide, was soldered around a 26 inch bicycle wheel thus making a circular band. The maze pattern was made of 1½ and 4¼ inch lengths of No. 12 galvanized wire soldered to this band, after the plan indicated in Fig. 1. The junction points, termed points of choice, are the smoothed heads of brass bolts. That certain 'land marks' might be had to facilitate the learning of the maze, washers were placed under the bolt heads at intervals as shown in the figure. It will be seen that the maze had 15 successive sections, each section furnishing a choice of 5 possible paths, 4 of which could be blocked off leaving the fifth as the correct path. The method of blocking was simple enough—a loop of small copper wire was passed across the path as indicated by the crosses in Fig. 1. Here it should be pointed out that the chief difference between this and other finger mazes is in respect to the behavior in blind alleys. In the usual maze the subject retraces his way at

once as soon as he is aware of entering a blind alley, but in this maze he has no opportunity of retracing since the maze is turning at a constant speed. He attempts no retracing, but merely lets his finger ride over the 'blind alley' wire and mentally notes his error seeking to correct it the next time through.

With the maze pattern completed the wheel was mounted and by a suitable

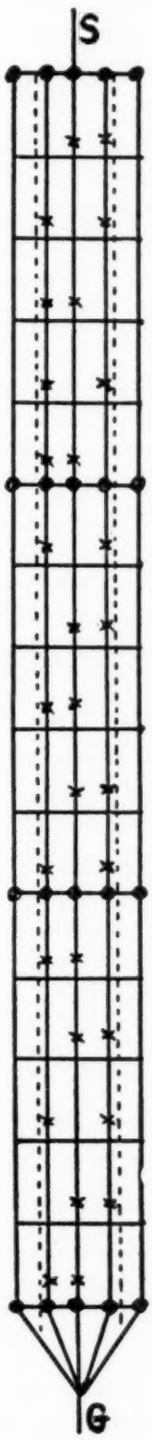


FIG. 1. The maze pattern as used. For this problem the entire outermost path on either side was blocked off; *S* indicates the starting alley and *G* the goal.

arrangement of reduction gears was linked to a motor with rheostat in series to the end that it could be rotated at varying fixed speeds. The entire apparatus was enclosed in a suitable case provided with a 5 by 8 inch working window on the upper side. When rotated the maze passes just beneath this window and the subject tracing the maze with his index finger permits it to pass continuously under his touch. To have a correct notion of the completed apparatus one needs to recall that the pattern as depicted in Fig. 1 actually bends back upon itself so that the goal alley, *G*, is continuous with the starting alley, *S*. Thus the subject may run the maze trial after trial with no interruptions of any sort.

Preliminary work soon revealed that the 5-choice pattern furnished a more difficult problem than needed in our present investigation so we blocked off the entire outermost path on either side by passing a small rope around the band as indicated by the broken lines of Fig. 1. This gave us a 3-choice maze pattern. After working with many subjects the following routine was adopted as standard procedure for our main experiment. Seated before the apparatus, the subject was given a brief description of the usual type of finger maze. He was then permitted to look at one section of the maze and had an opportunity to touch it and to trace as three more sections turned under his finger. Further needed instructions were then given, blindfolding goggles were placed on him, and the learning period started. The maze turned continuously so that he took trial after trial with no intermission. He was told each time the starting alley came under his touch, though this was suitably marked and all subjects soon came to recognize it by touch. If a subject desired, a one-minute rest interval was taken at the end of 15 or 20 trials. Two successive errorless trials were taken as the criterion of mastery and the learning was completed at one sitting.

In addition to the constant speed advantages which this maze offers two further significant advantages should be pointed out. Maze patterns of almost endless variety and presumably with the same degree of difficulty can be easily arranged; all that is involved is the changing of the wire loops indicating the blind alleys. Maze patterns of varying degrees of complexity, *viz.*, from two to five choices at each section, can be made. Furthermore there is evidence that the reliability of the maze is quite high. Using a small group of subjects and correlating the error score of the odd vs. even trials we found $r = .85+$. There is reason to believe that the reliability would be considerably higher if experienced subjects were used.

Results

The first investigation made with this constant speed maze has been a study of the relationship between speed per trial and efficiency of learning. Sophomore and junior students, 35 women and 25 men, were used as subjects. These 60 subjects were divided into 3 equal groups, each group running the maze at a different speed per trial. For Group A the maze made one revolution per 50 sec.; for Group B one revolution per 60 sec.; and for Group C one revolution per 70 sec. The procedure as outlined above was followed with each subject.

A summary of their work appears in Table 1, which shows the number of trials required, the number of errors made, and the time required for the average subject. That the speed

TABLE 1

SUMMARY OF RECORDS FOR THE COMPLETE LEARNING OF THE MAZE

Group	Av. Number of Trials	Av. Number of Errors	Av. Time Required
Group A 50 sec.	45.1 ± 2.98	277.2	37.58 min.
Group B 60 sec.	44.2 ± 2.55	270.6	44.20 min.
Group C 70 sec.	39.0 ± 2.48	226.0	45.50 min.

with which a subject is forced to thread his way through the maze is significant is very evident. This is most clearly seen in a comparison of the 50-sec. group with the 70-sec. group. The average number of trials for the 50-sec. group is 45.1 ± 2.98 as against 39.0 ± 2.48 for the 70-sec. group, a difference of 6.1

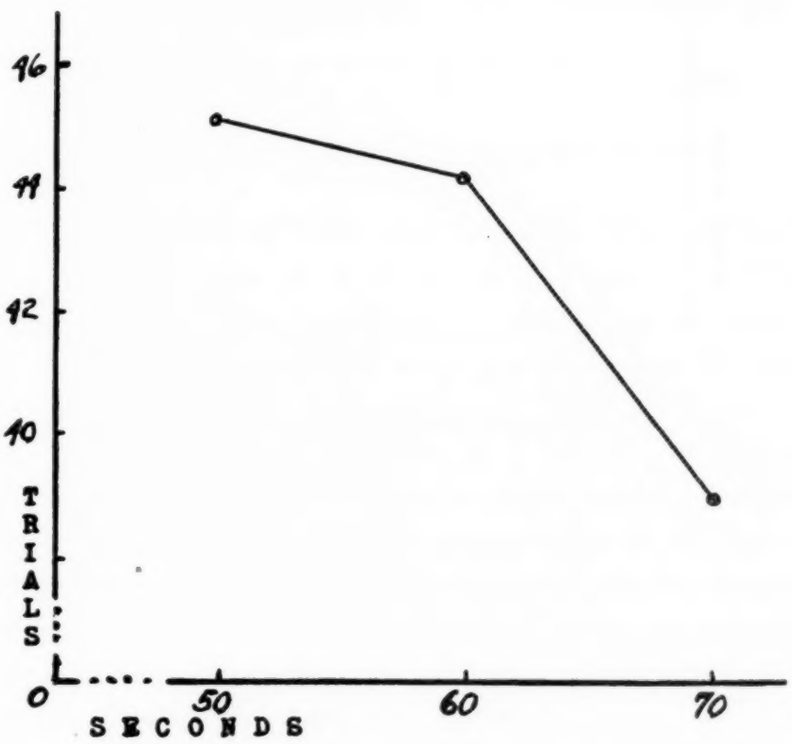


FIG. 2. Relation between the no. of trials required and speed.

trials. That this is a real difference seems evident when the P.E. of the difference is calculated; the chances are 85 out of 100 that the difference is greater than 0. The difference found between the 50-sec. group and the 60-sec. group is not large enough to be statistically reliable, though doubtless it would prove to be a real difference if sufficiently large groups could be used.

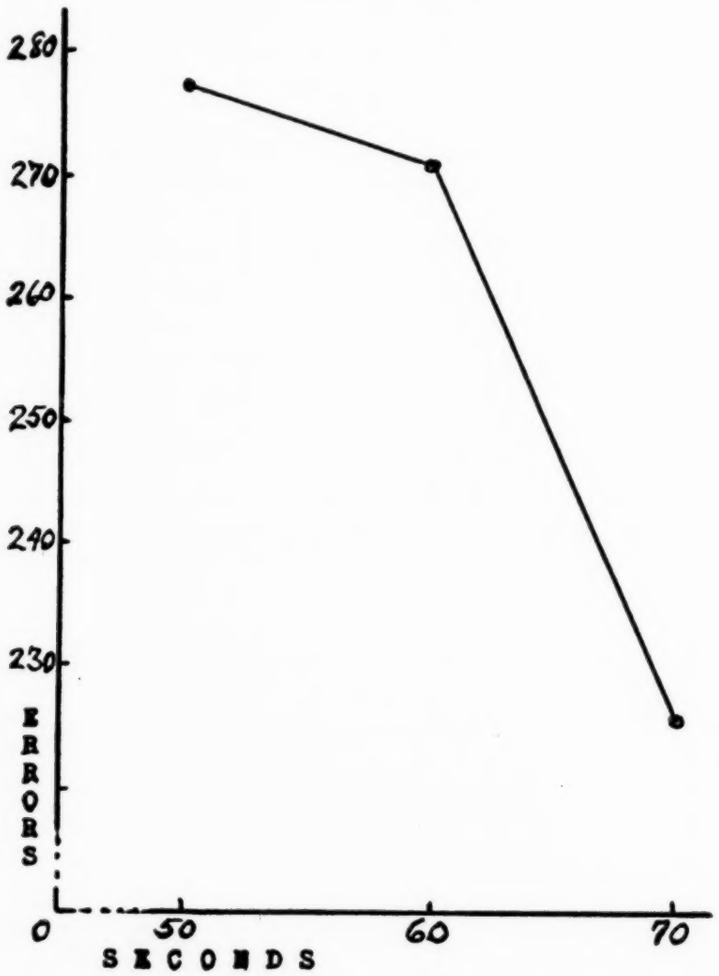


FIG. 3. Relation between the no. of errors and speed.

It will be noted, too, that the total number of errors is greater for the 50-sec. group than for the 70-sec. group. In the first named the average subject makes 277.2 errors, while in the latter group he makes 226.0 errors. Yet another difference is seen; the average learning time for the 50-sec. group is 37.58 min. while that for the 70-sec. group is 45.50 min. In other words though a Group C subject learns in fewer trials

yet his total learning time is 21 percent longer than that of a Group A subject. These relationships are graphically represented by the curves in Figs. 2, 3 and 4.

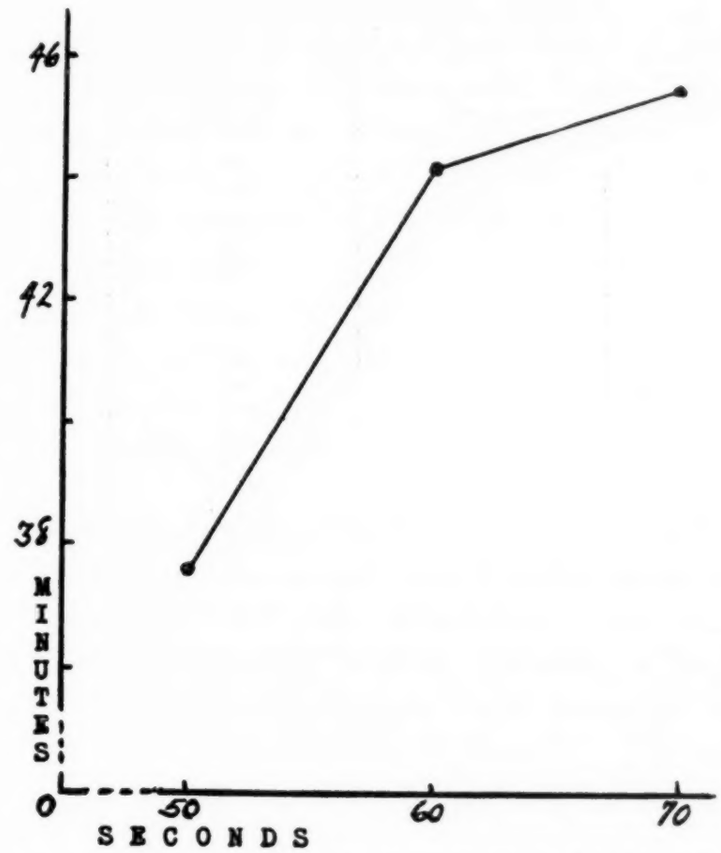


FIG. 4. Relation between the av. time required and speed.

Within the limits of this experiment, when subjects are forced to thread a maze at a given fixed speed each trial, the following facts have been established: (1) The average number of trials required for complete learning increases as the speed per trial increases. (2) The average number of errors increases as the speed per trial increases. (3) The average time required for complete learning decreases as the speed per trial increases.

Another matter of some interest concerns the shape of the learning curve for this function. Kjerstad curves were plotted as the most satisfactory way of presenting the matter. Curves were drawn for each individual subject and the errors graphically ascertained as at the end of each tenth of his

learning. The resulting averages are gathered in Table 2. In Fig. 5 the curves for the 50-sec. and the 70-sec. groups are

TABLE 2

ERRORS PER TRIAL AS AT END OF EACH TENTH OF LEARNING FOR THE AV. SUBJECT

Tenth	Group A (50 sec.)	Group B (60 sec.)	Group C (70 sec.)
1st	9.5	9.5	9.5
2nd	8.8	9.1	8.9
3rd	8.1	8.2	7.8
4th	7.2	7.3	6.9
5th	6.5	6.3	6.1
6th	5.5	5.5	5.2
7th	4.9	4.7	4.4
8th	3.8	3.5	3.5
9th	2.7	2.5	2.5
10th	0.0	0.0	0.0

shown. The curve for the 60-sec. group was omitted to avoid confusion; an examination of the data reveals that the curve would be in close conformity with the two presented. The curves show a tendency toward positive acceleration; some may want to insist that they approximate to straight-line

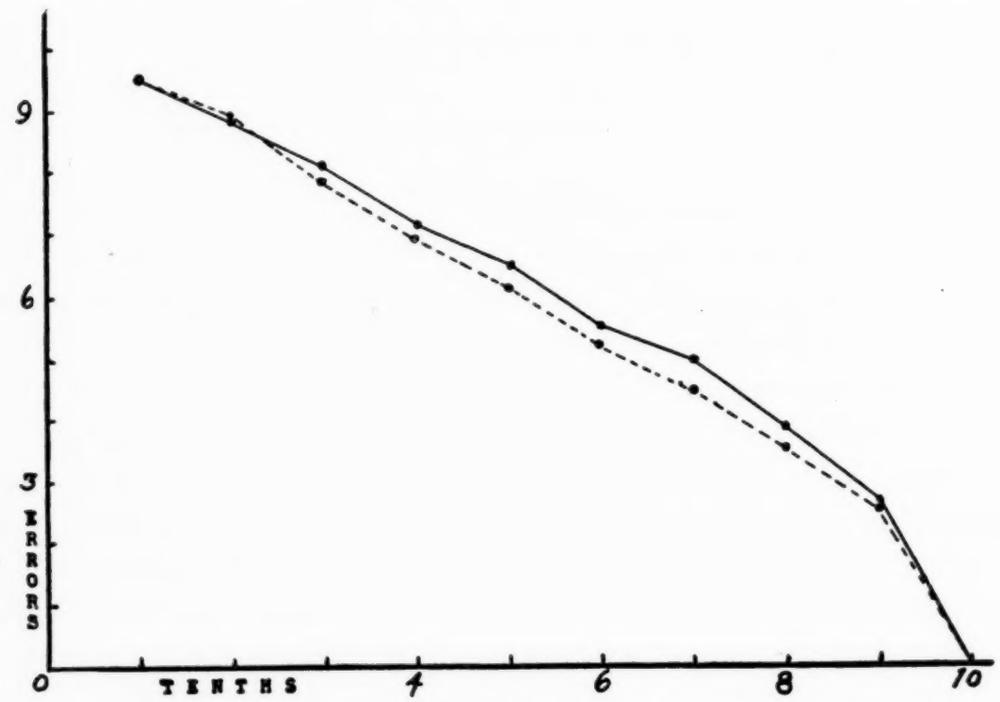


FIG. 5. Kjerstad curves; broken line represents 70-sec. group and solid line the 50-sec. group.

curves. In this connection it should be pointed out that an examination of the individual curves would reveal that approximately two-thirds of them are definitely accelerated positively; the remaining third are slightly S-shaped; this latter fact, of course, decreases the amount of positive acceleration which shows in any composite curve.

Still another question to be raised has to do with the order in which errors were eliminated. By way of answering this question we have analyzed the records of the 50-sec. group. It will be remembered that the maze, by virtue of the 'land marks' used, falls naturally into 3 segments. We determined the number of errors made in segments 1, 2 and 3 for successive fifths of each subject's work on the maze. The results are presented in Table 3. An inspection of this table readily

TABLE 3

AV. ERRORS IN THE 1ST, 2ND, AND 3RD SEGMENTS OF THE MAZE FOR SUCCESSIVE FIFTHS OF THE LEARNING

Segment	1st 5th	2nd 5th	3rd 5th	4th 5th	5th 5th
1	25.4	14.3	3.9	1.7	.8
2	29.2	27.7	23.4	14.4	5.7
3	30.2	27.9	26.4	22.9	18.4

The table includes only the 20 subjects of Group A.

reveals the rapid and early elimination of errors in the first segment, the less rapid elimination of errors in the second segment, with the third segment showing but slow elimination of errors even to the last fifth. An examination of the curves in Fig. 6 brings out these facts even more definitely. Though three subjects proved to be exceptions to this general rule, the second segment being the last learned in their case, still it would seem fair to state that the order of error elimination is definitely progressive from the first part of the maze to the last part.

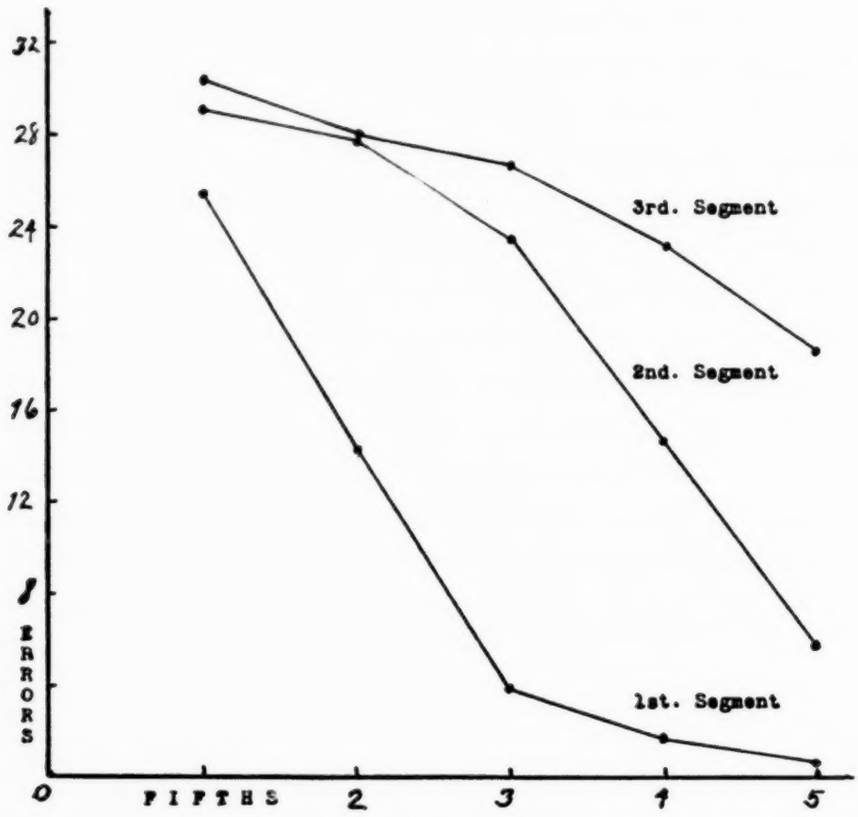


FIG. 6. Showing the av. errors made on each segment in successive fifths of the learning.

SUMMARY

The findings of this investigation in which the subjects were required to maintain a fixed speed per trial in threading their way through a maze may be summarized thus:

(1) The number of trials required for complete learning increases as speed per trial increases.

(2) The total number of errors increases as speed per trial increases.

(3) The time required for complete learning decreases as speed per trial increases.

(4) The learning curves show positive acceleration.

(5) The order of error elimination is definitely progressive from the first part of the maze toward the last.

(Manuscript received July 28, 1938)

STUDIES IN CONFIGURAL CONDITIONING. II. THE EFFECT OF SUBJECTS' ATTITUDES AND OF TASK-SETS UPON CONFIGURAL CONDITIONING

BY G. H. S. RAZRAN

Columbia University

The Problem

In a previous study by the writer (**10**) configural conditioning—conditioning to a pattern of stimuli with no conditioning to the component stimuli of the pattern—manifested itself in three adult human subjects from the very beginning of their conditioning training. This finding is at variance with a number of investigations—particularly from Beritoff's laboratory—with animals in which such conditioning invariably appeared only long after conditioning to individual components had been established (**1–4, 11**). Since the writer's S–R set-up did not differ materially from that of the other experimenters, the discrepancy in results must apparently be attributed to the organisms or subjects experimented with, a supposition having some support in the fact that human subjects in general form CRs more readily to compound than to single stimuli (**5, 7**). The question then arose, Is this difference between human and animal configural conditioning ultimate, or is it merely an outcome of the special methodology and task-set of usual CR experimentation? Could *emergent* rather than *initial* configural conditioning be regularly established in human subjects? What would the conditions for such establishing be? and What in general are the determinants of this or the other developmental form of configural conditioning? Some answer to these questions was sought in the present study.

Procedure

The writer's general salivary technique with adult human subjects has been described before (**9–10**) and will not be

further detailed. It consists, first, of measuring salivation by increments in weights of dental cotton rolls (1.5 × 0.5 in.) inserted under the subjects' tongues for a short period of time, usually one minute. To prevent evaporation, scale-corrosion and absorption, the rolls are weighed in small envelopes and reweighed in the envelopes immediately after the removal of the cotton from the subjects' mouths. Since the cotton-in-the-mouth is by no means a totally inactive stimulus, periods of control salivation must always be rotated with experimental periods, but the weighing itself need not be more accurate than to one centigram, mg. accuracies being as a rule an unnecessary refinement. Secondly, the technique involves presenting a series of stimuli during eating periods of 2–4 minutes and misinforming the subjects about the purpose of the experiment so as to preclude disturbing subjective attitudes and association-sets. Such misinforming was found to be successful only when series rather than single stimuli-to-be-conditioned were applied and when comparatively long eating periods were allowed. Effects of eye-fatigue upon digestion with visual stimuli, influence of music upon salivation with musical tones, and imaginary memory problems with nonsense syllables were some of the simulated objectives used in the past.

In the special procedure of the present experiment, the stimuli-to-be-conditioned were in all cases flashings of red and green 2.5 volts' lights, the eating periods always lasted for two minutes, and the testing periods were of 6-minutes duration. The manner of presenting the stimuli and the tasks in which they were imbedded differed, however, widely with each of the three groups of subjects in the experiment. With group A, 40 intermittent rhythmical flashings—red→red, green→green, red→green, green→red in equal and rotated sequences—were merely presented in the usual way, while the subjects chewed gum, sucked at lollipops, or ate small pretzels. But the subjects in group B supposedly learned an electrical bolt-head maze while consuming their food. Whenever they made a right move, a green light would flash, a wrong move, a red would flash, the moving, flashing, and eating continuing for two minutes and the flashes becoming meanwhile associated

with the food. The number of flashes during the two minutes were of course not exactly equal to 40, but they seldom went below 30 or above 50. The maze itself was practically unsolvable, permitting only a sufficient diminution of errors to produce an illusion of achievement (The ratio of right to wrong moves, or green to red flashes, was about 4 : 5 in the beginning of the experiment and 5 : 4 towards its end). Again, with group C the task-set was in a way a combination of A and B. These subjects ate while observing other subjects solve the electrical bolthead maze. Finally, in the testing periods of all three groups, the magnitudes of the subjects' salivations in one-minute periods to single flashes of red or green lights and to alternate flashes of red and green lights were determined in terms of the control salivations during those periods. In all, 8 trials—a training period of two minutes and a testing period of six minutes—were made each experimental session, and 5 sessions or 40 trials with each subject. The subjects were 12 college undergraduates, paid by N. Y. A. at 50 cents an hour, and the experiment was conducted in a dimly lighted, fairly sound-proof room, between three and five o'clock in the afternoon.

Results and Discussion

The results are presented in Tables 1–3 and in Fig. 1. In the Tables are given, trial by trial, the means of the conditioned salivations for each of the three groups of subjects and for each of the four stimuli tested—red→green, green→red, red alone, green alone. In the Figure the data for the two kinds of single stimuli and two kinds of compound stimuli have been combined and are presented as differences between compound and componental conditioning—the latter as the subtrahend. In all cases the conditioned salivations are differences between salivations in control and in conditioned periods, special control periods having been used to eliminate the excesses of accumulated saliva in the periods immediately following the eating peroids. The salivations were also, to some extent, affected by the particular times in the testing periods that they had been taken, but this factor was ruled

TABLE 1

COMPOUND AND COMPONENTAL SALIVARY CRs OF FOUR ADULT HUMAN SUBJECTS (GROUP A: STIMULI PRESENTED IN USUAL MANNER) TO TWO VISUAL STIMULI

Figures represent means of conditioned salivations in centigrams per one-minute periods.

No. of Trial	Compound Stimuli		Component Stimuli	
	Red→Green Lights	Green→Red Lights	Red Light	Green Light
1	19	21	5	4
2	22	18	2	5
3	18	14	0	1
4	23	12	6	9
5	27	11	9	7
6	19	13	8	5
7	20	29	4	7
8	21	27	7	8
9	15	18	4	10
10	14	17	9	7
11	24	26	11	15
12	30	20	10	16
13	22	27	8	9
14	23	29	10	17
15	19	32	6	3
16	23	16	7	3
17	20	20	8	4
18	22	18	2	10
19	18	14	6	5
20	19	21	7	9
21	17	15	2	12
22	20	14	8	10
23	27	28	12	13
24	28	30	10	14
25	23	19	11	8
26	19	17	6	9
27	28	32	17	19
28	26	25	9	9
29	16	11	3	7
30	18	15	4	6
31	28	34	14	12
32	29	31	11	15
33	16	12	18	19
34	14	8	4	9
35	10	6	13	17
36	4	12	10	8
37	11	9	16	12
38	14	12	14	12
39	0	11	12	10
40	6	9	14	14

TABLE 2

COMPOUND AND COMPONENTAL SALIVARY CRs OF FOUR ADULT HUMAN SUBJECTS TO TWO VISUAL STIMULI. GROUP B: STIMULI PRESENTED AS SIGNALS IN SOLVING A MAZE

Figures represent means of conditioned salivations in centigrams per one-minute periods.

No. of Trial	Compound Stimuli		Component Stimuli	
	Red→Green Lights	Green→Red Lights	Red Light	Green Light
1	−2	−1	13	11
2	−3	0	18	16
3	2	4	14	20
4	3	0	7	16
5	1	5	4	11
6	2	8	7	20
7	4	6	12	16
8	0	2	11	15
9	0	0	14	20
10	−2	0	9	15
11	4	6	18	21
12	8	5	10	16
13	10	9	21	24
14	9	8	19	20
15	13	2	10	8
16	11	5	13	16
17	12	9	20	14
18	10	10	11	20
19	9	−4	8	11
20	2	2	12	10
21	3	5	13	19
22	1	6	23	16
23	0	0	14	20
24	−4	−6	12	16
25	3	7	20	22
26	8	1	15	10
27	10	2	11	14
28	8	10	15	14
29	14	13	11	19
30	10	9	10	21
31	23	21	19	27
32	16	17	10	21
33	14	20	14	15
34	11	16	22	18
35	23	25	12	16
36	17	14	15	20
37	21	19	9	10
38	18	23	16	14
39	18	19	8	10
40	21	17	7	10

TABLE 3

COMPOUND AND COMPONENTAL SALIVARY CRs IN FOUR ADULT HUMAN SUBJECTS TO TWO VISUAL STIMULI. GROUP C: STIMULI PRESENTED AS OBSERVING SIGNALS IN SOLVING A MAZE

Figures represent means of conditioned salivations in centigrams per one-minute periods.

No. of Trial	Compound Stimuli		Component Stimuli	
	Red→Green Lights	Green→Red Lights	Red Light	Green Light
1	3	4	1	2
2	5	6	4	3
3	10	9	7	11
4	9	8	−6	8
5	4	4	6	12
6	5	−2	−3	−3
7	18	21	6	14
8	14	12	12	9
9	18	23	5	12
10	15	20	10	16
11	18	12	9	11
12	10	14	12	7
13	11	9	11	8
14	15	17	12	14
15	21	19	18	14
16	20	17	23	21
17	24	28	13	24
18	15	22	20	17
19	14	16	26	15
20	18	11	16	15
21	24	30	20	12
22	21	18	21	16
23	19	14	20	14
24	11	13	22	19
25	18	19	20	18
26	17	22	21	19
27	13	14	9	13
28	15	12	11	12
29	23	17	16	20
30	19	20	12	17
31	14	18	8	5
32	12	11	10	8
33	10	10	6	11
34	7	7	3	7
35	7	13	2	−1
36	11	14	8	6
37	9	8	9	8
38	11	15	10	0
39	8	12	11	7
40	14	13	9	12

out by rotation which, as stated above, had been one of the chief features of the general procedure of the experiment.

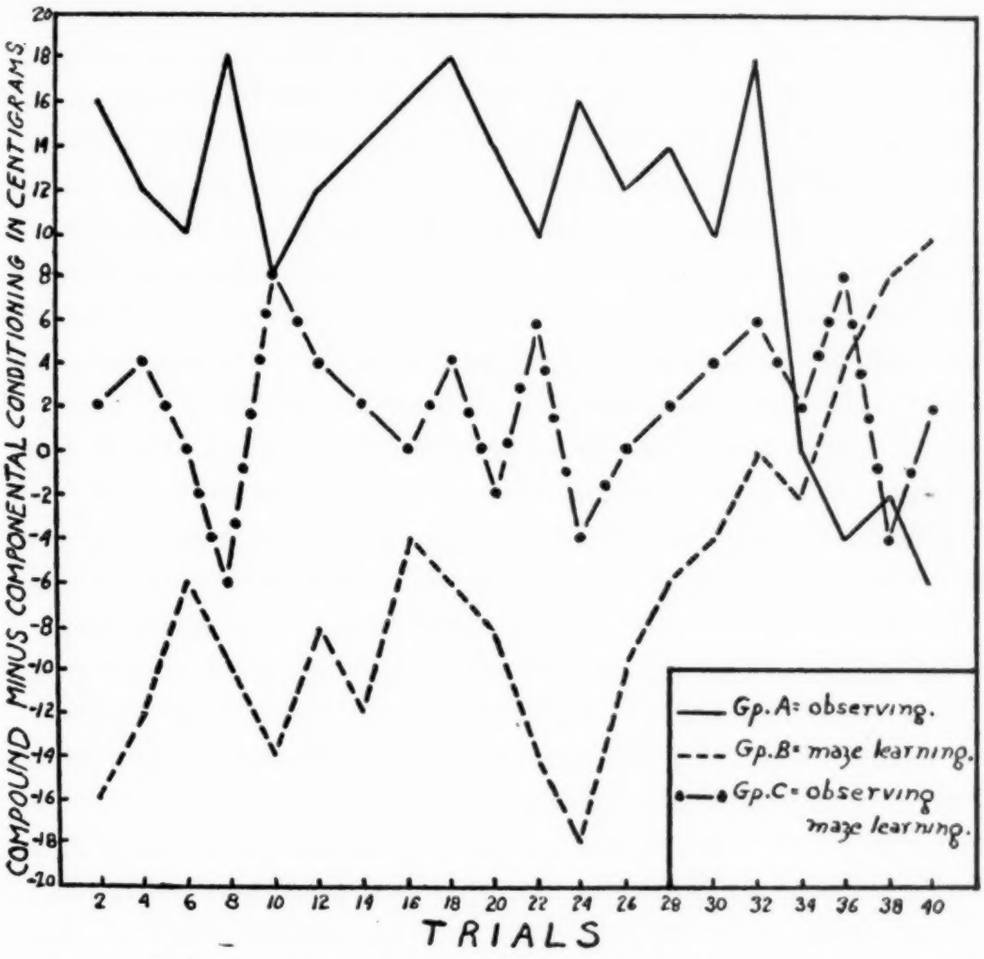


FIG. 1. Differences between salivary CRs of 12 adult human subjects to a compound stimulus (red→green or green→red lights) and to its components (red or green light alone).

As seen from the results, some answer to the questions propounded in the first part of the paper may now be made out. First of all, it is obvious that even in human subjects patterned stimuli do not always have a to-be-conditioned advantage over non-patterned stimuli, or, in other words, configural conditioning does not always appear at the very beginning of the conditioning training. In group B it was the single stimuli that were, for the most part, most effective, configural conditioning emerging in some degree only in the final stage of the training, while in group C the configural conditioning never became completely stable. Secondly, it is

clear that task-sets and attitudes may be important determinants of the strengths, the stages as well as, apparently, of the total presence of configural conditioning. The very pronounced differences between the conditionings of the three groups could not have arisen because of differences in the sensory fields of the conditioned stimuli, since these had been equal in all groups. Thirdly, when component stimuli of a patterned situation are of some differential interest—or value or significance or meaning—to the subjects, the conditioning tends to be componental in kind. In group B the differential interests of the component stimuli were direct, their functions as different signals in the solution of the maze. In group C these differential interests were indirect, by proxy and identification, but in both cases interest-differentials did exist. Fourthly, configural conditioning apparently manifests itself best when the subjects' attitude is—what might be called—passive-perceptual or pure-observational, as in group A. However, it is not inconceivable that even here some vested extra-sensory interest—preferential or esthetic—grounded in the subjects' pasts and personalities might have been operative, as indicated by the fact that towards the end of the training and the onset of ennui configural conditioning waned in all subjects, and that in one subject (previous study, **11**) it did not develop to begin with. Fifthly and finally, the results corroborate the writer's earlier findings that configural conditioning is highly dynamic in nature and that the variables with which its developmental changes correlate are to be sought in the subjects and their interests and attitudes rather than in the sensory fields and their forces and organizations.[1]

In considering the bearings of these results upon the general theory of the role of patterns and configurations in behavior and in modifiability of behavior, the limitations of the present study and the restricted range of its stimuli are fully realized. Nevertheless, some statement seems to be

[1] The results also confirm partly the writer's earlier finding (**10**) that stimuli serving as right cues in solving a maze differ in their conditioning values from those used as wrong cues. The differences—red alone vs. green alone in group B—are, however, not very clear-cut in this study partly, perhaps, because the learning was only partial and very slow.

justified, particularly since no differential behavior of human glandular action to patterned [2] and non-patterned stimuli has previously been reported and no discussion of configurations in its light made. Upon the basis of his own series of results and with due regard to experimental evidence from other sources, it is the writer's view that, while patterns may no doubt be genuine determinants of behavior and should by no means be omitted from consideration in research and theory, their role and value have, in the hands of the Gestalt psychologists, become all to exaggerated, too reified and stratified. Patterns and patternization are specific problems to be investigated under specific conditions and relations to specific constituents and not general world-view principles, all-pervading in theory and ubiquitous in applicability. There may be as many laws of patterning as stimuli to be patterned and at any rate there may not be just a single, fully circumscribed set of them. Neither is patternization in human beings always so primary and compelling, a cause rather than a result, inherent in sensory fields and their forces, a sort of preformed 'spontaneous and compulsory grouping of data in an organized environment' (**6**). The contrary appears often to be the case. The chief locus of organization resides in Man, in his own 'internalized' environment, in his accumulated habits and capacities, his ever-changing interests and attitudes.

Summary

1. Salivary CRs have been established in 12 adult human subjects to a compound stimulus (successive flashes of red and green lights) and to its components (single flashes of a red or a green light).

2. In 4 subjects (group A) the stimuli-to-be-conditioned were presented in the usual manner, in 4 others (group B) they were presented as right and wrong signals in a bolthead maze

[2] The writer's use of patterned stimuli and of pattern may need redefining here. It is used by him to denote any supra-summative action that a combination of more than one stimulus may exhibit, or, in other words, when the behavior of an organism to a + b + c + ··· n cannot be predicted from behavior to a, b, c, ··· n acting separately. Red→green and green→red flashes of lights were thus shown to be patterned stimuli or patterns with respect to single flashes of red or green lights.

which the subjects were supposedly to solve, while the remaining 4 subjects (group C) observed the stimuli as others solved the maze. In all subjects the stimuli were combined with eating periods of chewing gum, sucking at lollipops, or eating small pretzels.

3. The compound stimuli were much more effective than their components in group A, but the components were more effective in group B, with zigzagging tendencies in group C. Towards the end of the training some reversals in the forms of the conditioning occured in the first two groups.

4. Inasmuch as the visual sensory fields of the stimuli-to-be-conditioned were equal in all three groups, it is concluded that the differing task-sets and attitudes produced the differences in results between the groups. It is assumed, for instance, that the interest-differential between component stimuli in group B induced an analytical attitude which presumably resulted in componental conditioning, and that in group A the lack of such an interest-differential and the more detached visuo-perceptual set favored some sort of a synthetic attitude. In group C, on the other hand, the zigzagging of the types of conditioning may have arisen from a conflict between the analytical and the synthetical attitude, which is plausible in view of the fact that the interest-differential of the component stimuli was weak and indirect in this group.

5. It is further concluded that the patternization of conditioned behavior—and possibly of all behavior—of adult human subjects is more affected by the habits, attitudes, sets, and interests of the subjects than by the sensory fields of the stimuli, their adjudged forces and organizations.

References

1. Beritoff, J. S., *Individually-acquired activity of the central nervous system.* Tbilisi: GIZ, 1932, pp. 470.
2. Beritoff, J. S. and Bregadze, A., Physiology of animal behavior in complex situations: individual reactions of animals to complex sound stimuli, *Med. Biol. Zh.*, 1929, **5** (No. 3), 131–151.
3. Bregadze, A., The formation of individual reactions to a complex of musical tones in dogs, *Trud. Instit. Beritashvili*, 1937, **3**, 415–430.
4. Bregadze, A. and Tarugov, S., Individual reactions of rabbits to complex sound stimuli, *Trud. Instit. Beritashvili*, 1937, **3**, 431–447.

5. Israelson, Z. I., Topical differentiation of associated motor reflexes to dermal and muscular stimuli, *Izv. Imper. Voyenno-med. Akad.*, 1914, **28**, 73–78.
6. Koffka, W., *Principles of Gestalt psychology*, New York: Harcourt, Brace, and Co., 1935, pp. 715.
7. Kotliarevsky, A. N., Orientation-investigatory conditioned reflexes to simple and to synthetic stimuli in school children, *Eksper. Issl. Vyssh. Nerv. Deyat. Reb.*, 1933, 14–33.
8. Razran, G. H. S., Conditioned responses: an experimental study and a theoretical analysis, *Arch. of Psychol.*, 1935, **28** (No. 191), pp. 124.
9. Razran, G. H. S., Attitudinal control of human conditioning, *J. Psycho.*, 1936, **2**, 27–37.
10. Razran, G. H. S., Studies in configural conditioning. I. Historical and preliminary experimentation (in press).
11. Zeliony, G. P., Contributions a l'analyse des excitants complexes des réflexes conditionnels, *Arkh. Biol. Nauk*, 1910, **15**, 437–453.

THE SOCIAL FACILITATION OF LOCOMOTOR BEHAVIOR IN THE ALBINO RAT

BY WILLIAM M. LEPLEY

The Pennsylvania State College

The experiment to be reported was suggested by an incidental phenomenon which appeared in a previous study (1). In the first phase of this previous study the animals, albino rats, were run in isolation through a straight thirty-foot alley to a food goal. In the second phase they were run in pairs for several days in preparation for the last phase of the experiment, in which an attempt was made to induce them to compete for the food goal. A comparison of the mean time scores obtained under the first conditions with the mean time scores obtained under the second conditions revealed a significant difference which seemed to show that the animals ran faster while running in pairs. This difference was tentatively interpreted as resulting from social facilitation. This interpretation was offered with the caution that the obtained difference might represent nothing more than a difference between an earlier and a later phase of a learning process, since the runs in isolation preceded the runs in pairs.

The present experiment was planned and executed in an attempt to isolate the factor of social facilitation and to answer the question: Is the locomotor behavior of the albino rat susceptible to social facilitation?

The Experiment

The experimental squad consisted of eighteen animals, eight males and ten females. These rats were about one hundred days old at the beginning of the experiment.

The apparatus consisted of a straight unobstructed alley six inches wide, five inches high, and thirty feet long (inside dimensions). This alley was constructed of wood, painted a dull black, and provided with a top of wire mesh. The starting box was closed at the forward end by a vertically sliding gate. This gate was so wired that the opening thereof closed the circuit through a magnetic signal marker arranged

to record upon a constant speed polygraph. The goal box was situated six inches beyond the finish line which was arbitrarily established and plainly marked upon the floor of the alley. The distance between starting gate and finish line was exactly thirty feet. An animal's run was recorded as complete when any portion of the body crossed the finish line. The time of crossing was recorded on the polygraph by a magnetic signal marker which was manually operated by the experimenter. Running time was obtained to the nearest tenth of a second by reading the polygraph record with an appropriately graduated scale.

Throughout the experiment the animals were run after a starvation period of approximately twenty-three hours. The food reward consisted of a standard laboratory diet (2). After each day's performance the animals were fed to satiation upon this same diet. All experimentation was scheduled between 5:30 and 6:30 P.M., at which time extraneous noise was at a minimum. The ample, artificial lighting was held constant.

The experimental schedule was arranged so that the animals ran in isolation and in pairs on alternate days. Further, the females always ran in pairs on the days the males ran singly, and vice versa. The total performance period consisted of twenty-four consecutive days. Each animal was given two trials per day. No records were taken during the first four days. In other words, each animal was given eight preliminary trials, four in isolation, and four in company. The experimental period consisted of the remaining twenty days.

Results

According to this outlined procedure, forty time scores were obtained for each animal, twenty from isolated runs and twenty from paired runs. In the comparison of the mean scores for the two conditions, then, each condition was represented by three hundred and sixty scores. This comparison revealed an obtained mean difference of 0.4 second in favor of the paired runs. The mean score for the runs in isolation was 12.1 seconds. The mean score for the runs in pairs was 11.7 seconds. This difference of 0.4 second was found to be only 0.62 times its standard error of 0.65.[1]

In order to make certain that a significant difference, possibly occurring in some phase of the experiment, was not obscured by this treatment of the massed data, similar comparisons were made for each fifth of the total experimental period. The values for the successive fifths appear in the following summary table.

The two types of performance may be compared in another way. The mean scores computed from the massed data show

[1] The raw data from which the values reported in this study were computed are on file at the Department of Psychology of The Pennsylvania State College.

TABLE I

A Comparison of the Mean Time Scores in Seconds, Obtained under the Two Conditions and Computed for the Successive Fifths of the Total Experimental Period

Each value computed in this manner represents the mean of 72 measurements. N = 18.

	Mean Time Scores					
	Successive Fifths					
	I	II	III	IV	V	All Fifths
Isolated	14.0	13.6	11.4	11.2	10.2	12.1
Paired	14.0	12.1	11.5	11.5	9.3	11.7
$M_{diff.}$	0.0	1.5	−0.1	−0.3	0.9	0.4
$\sigma_{M_{diff.}}$	—	1.82	0.69	0.93	0.64	0.65
C. R.	—	0.83	0.15	0.32	1.41	0.62

that, within the female group, five animals were facilitated and five were distracted. Within the group of male animals three were facilitated, three were distracted, and two were apparently affected not at all.

Interpretations

The above statistics justify only a most cautious interpretation. Under the conditions of this experiment, it has not been demonstrated that the locomotor behavior of the albino rat is susceptible to social facilitation. In this respect these data contradict the data from the writer's previously reported study (1).

Summary

The experiment reported above was designed to answer the question: Is the locomotor behavior of the albino rat susceptible to social facilitation? Eighteen animals, eight males and ten females, were run through a straight, unobstructed, thirty-foot alley to a food goal under alternating conditions. Each animal made twenty runs in isolation. On alternate days each animal ran paired with another member of

the squad under conditions otherwise identical. A comparison of the mean time scores reveals no significant differentiating effect of the intentionally varied social factor.

(Manuscript received October 27, 1938)

References

1. Lepley, W. M., Competitive behavior in the albino rat, *J. Exper. Psychol.*, 1937, **21**, 194–201.
2. Ruch, F. L., Experimental studies of the factors influencing the difficulty of blind alleys in a linear maze, *J. Comp. Psychol.*, 1935, **20**, 23.